MSFC-465

IMAGE RPI Reawakens Plasmaspheric Refilling Research

D. L. Gallagher and Z. B. Smith

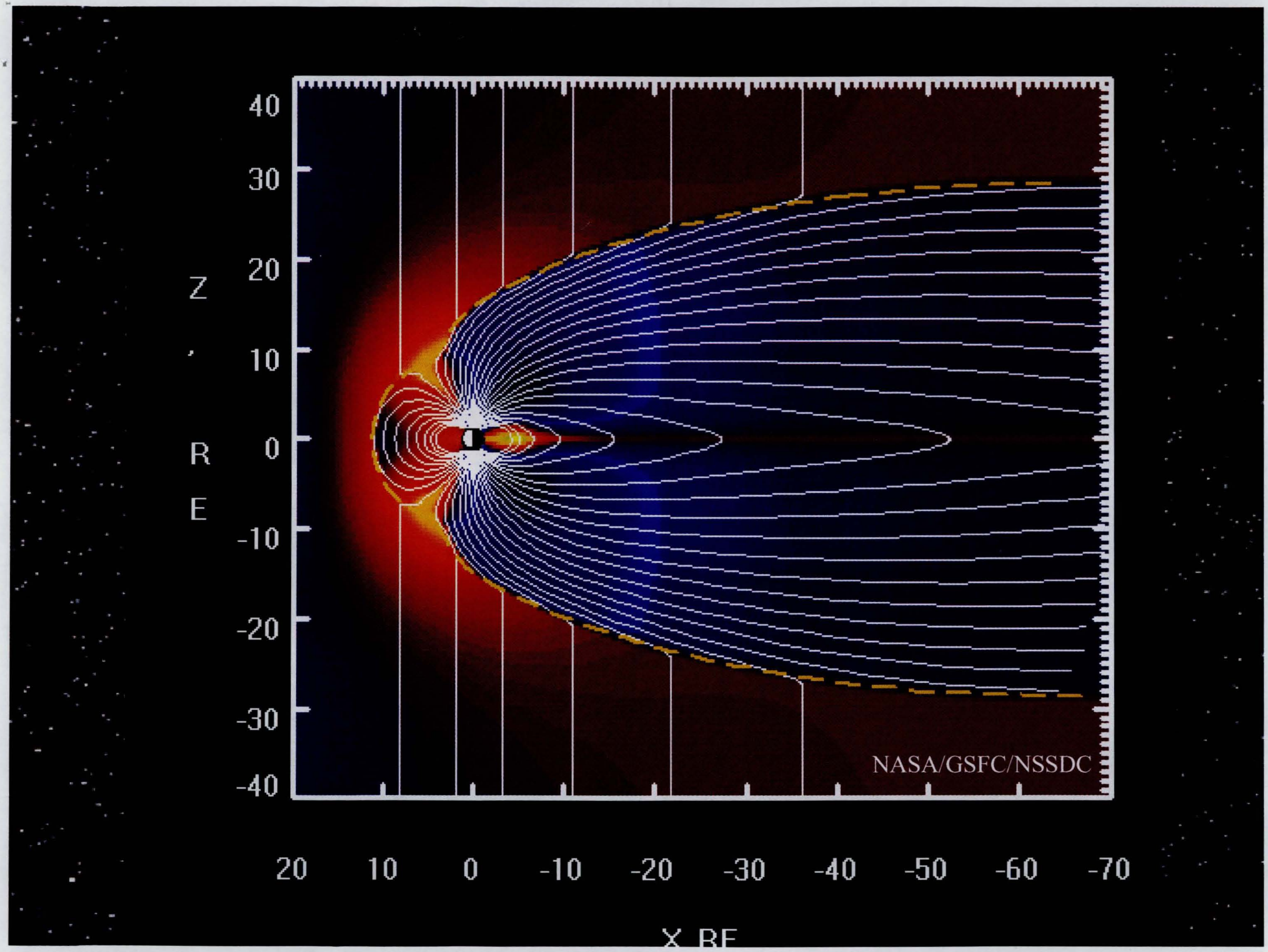
The plasmasphere is a toroidal region of cold plasma surrounding the Earth that results from ionospheric outflow and accumulation. The physics of refilling and the dynamics of this region have been studied for nearly 50-years. During that time many models have been proposed, but little has been done to test these models due to a lack of observational information. With the launch of the IMAGE Mission in March 2000 the Radio Plasma Imager has provided true field aligned density measurements that uniquely enable the testing of these models and a final determination of the physical processes important for the plasmasphere's recovery from storm-time conditions.

MSFC - 457 - Presentation

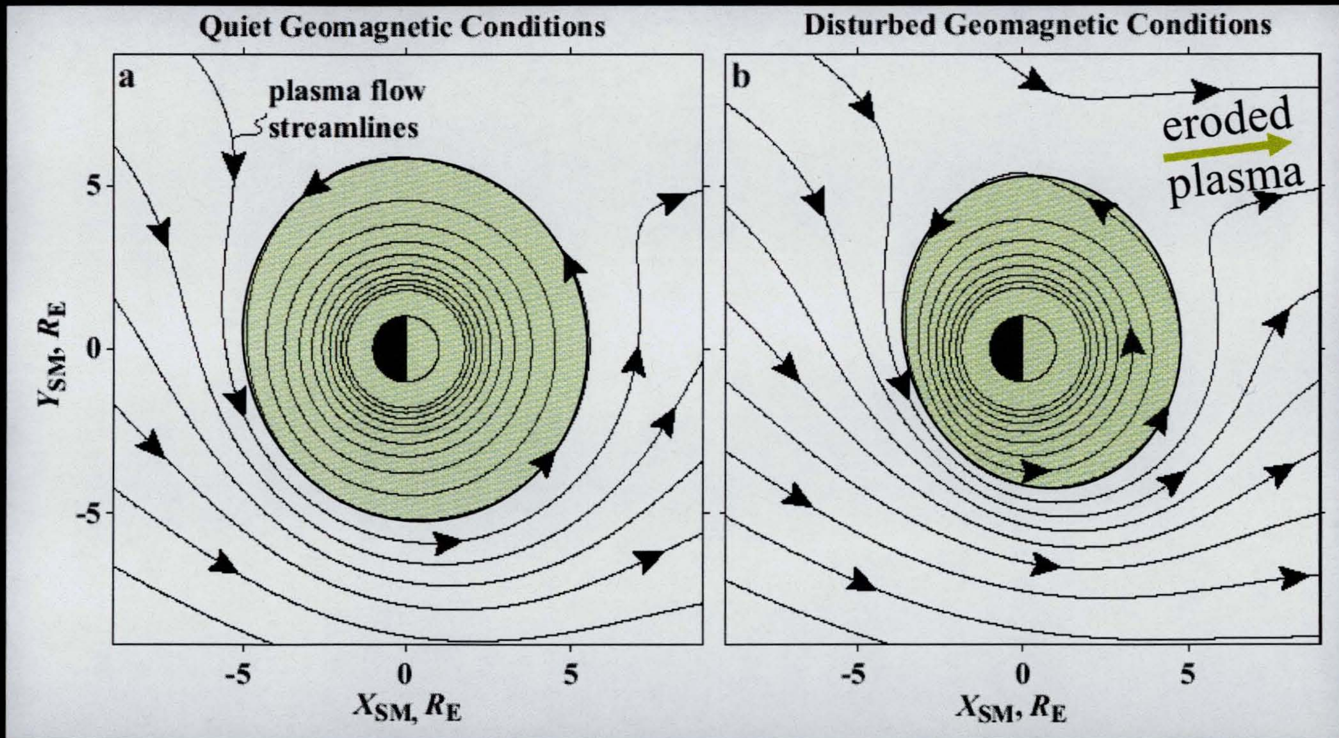
IMAGE RPI Reawakens Plasmaspheric Refilling Research

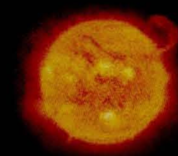
D. L. Gallagher and Z. B. Smith

- The Plasmasphere and Refilling
- Historical Context
- Measurement Starved
- IMAGE RPI Revolution


40
30
20
10
0
-10
-20
-30
-40
Z
R
E
NASA/GSFC/NSSDC
20
10
0
-10
-20
-30
-40
-50
-60
-70
X RE

Electric Field Driven Plasma Drift Dominates the Disposition of Thermal Plasma in the Magnetosphere

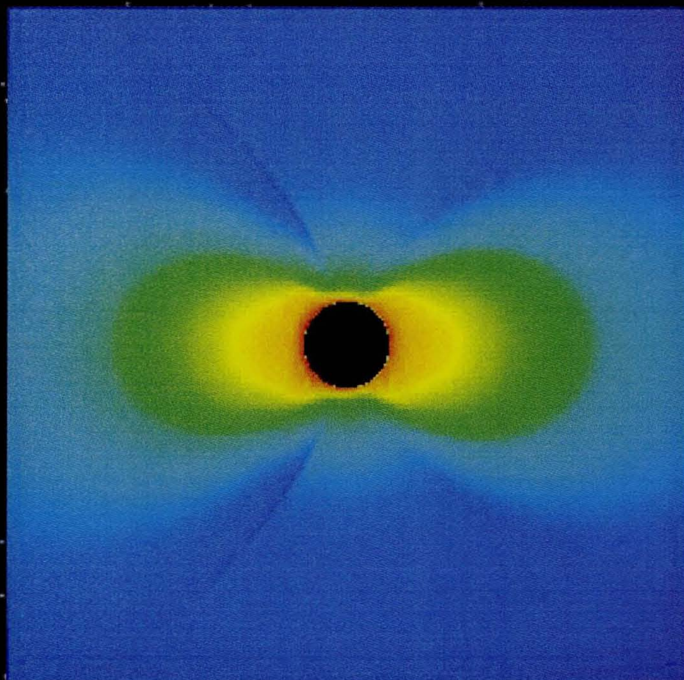


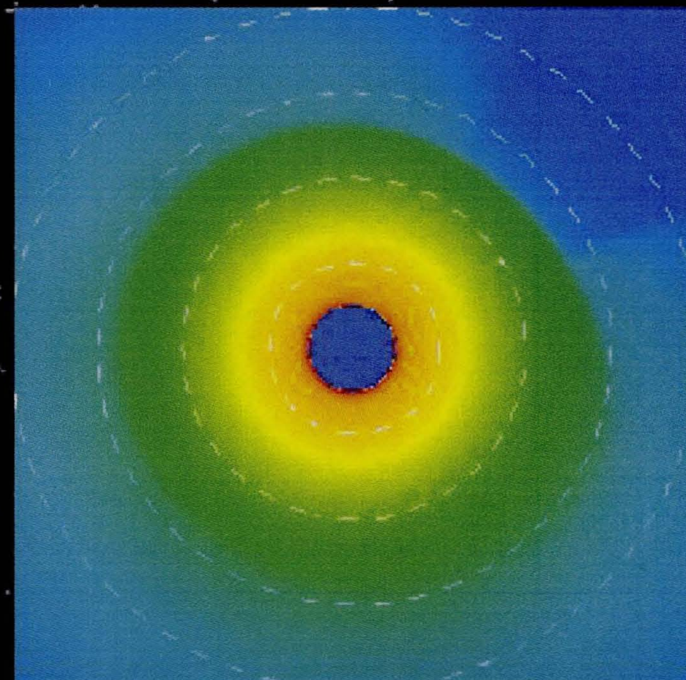


E5D, McIlwain, 1986

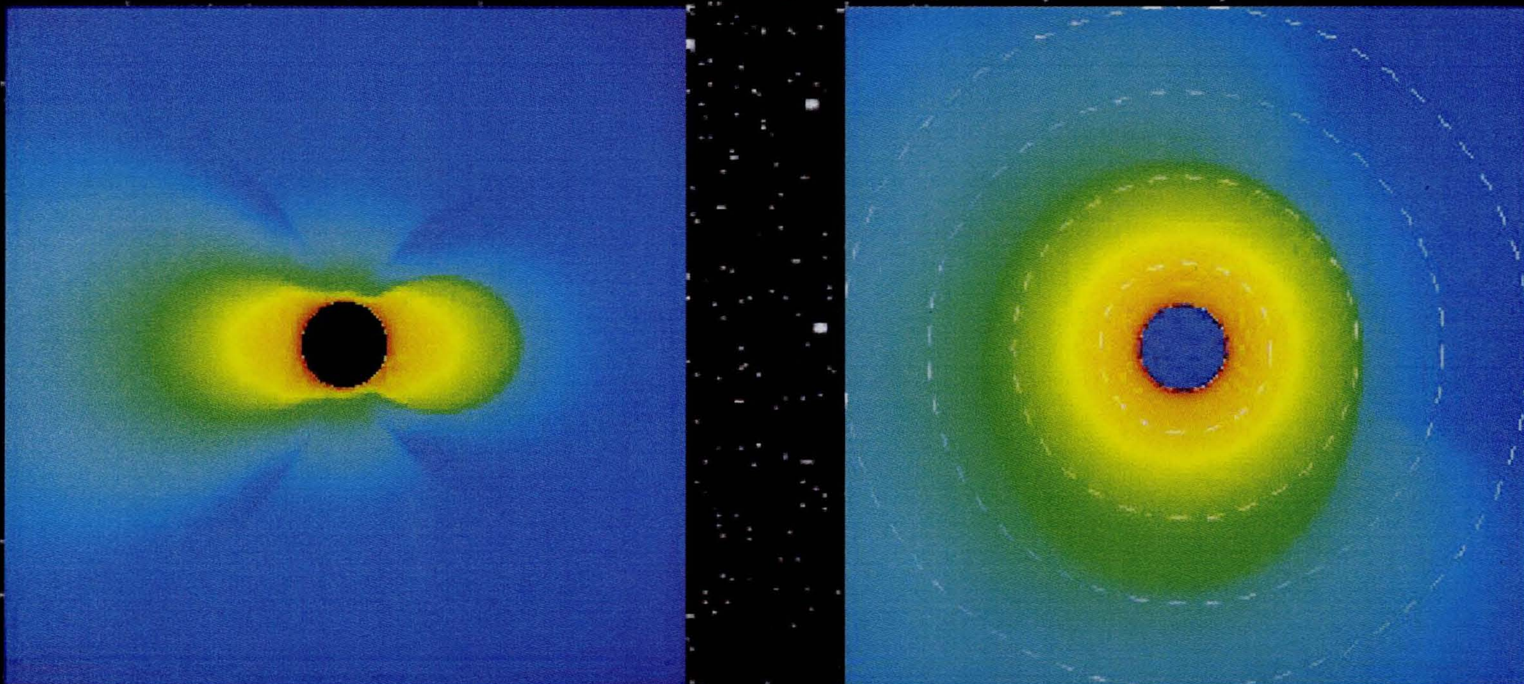
GLOBAL DYNAMICS OF THE EARTH'S PLASMASPHERE,
PhD Dissertation, Maria Spasojevic, 2003.

Quite Conditions

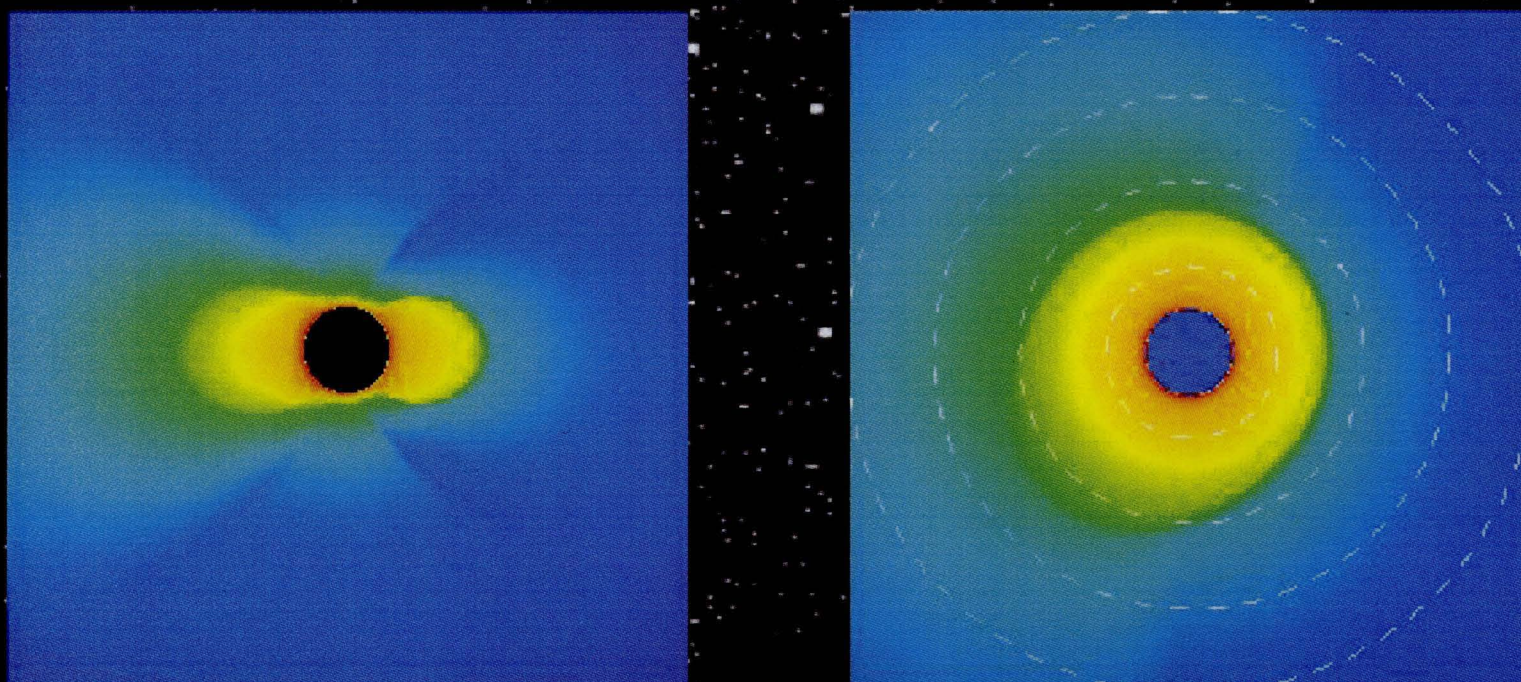




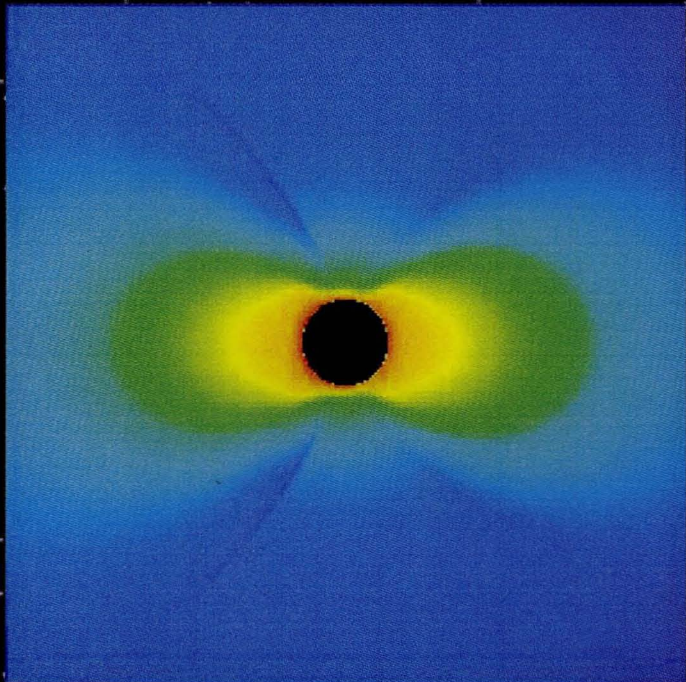
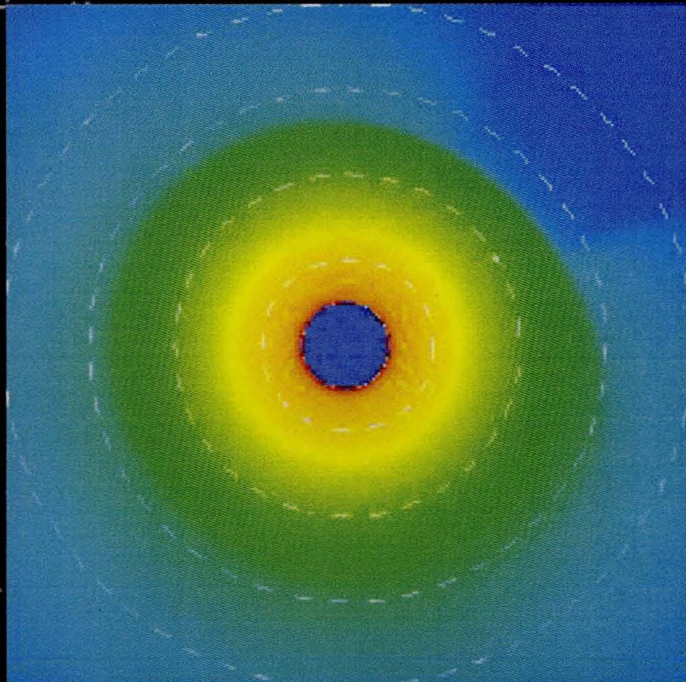
Moderate Conditions

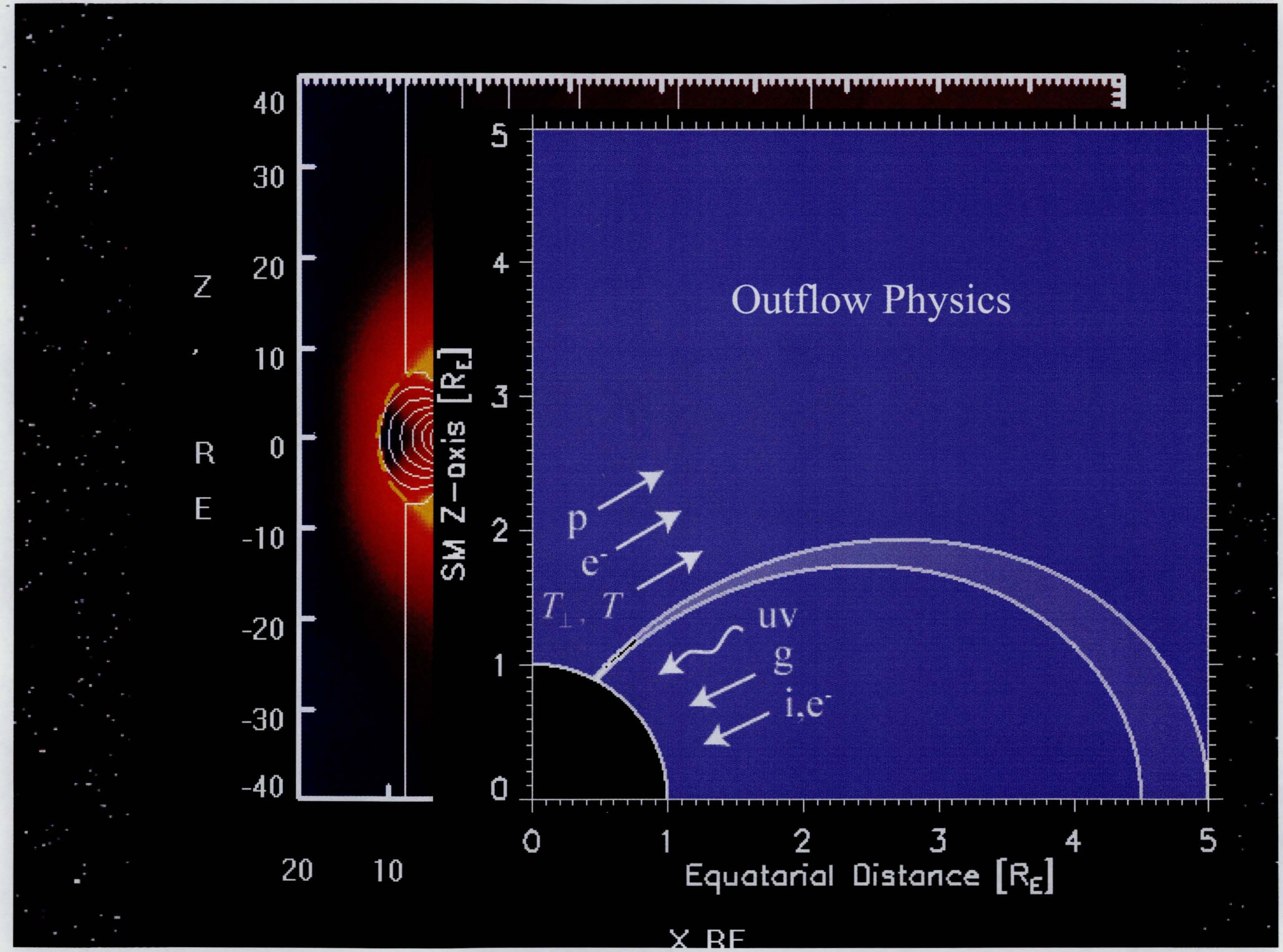


Active Conditions



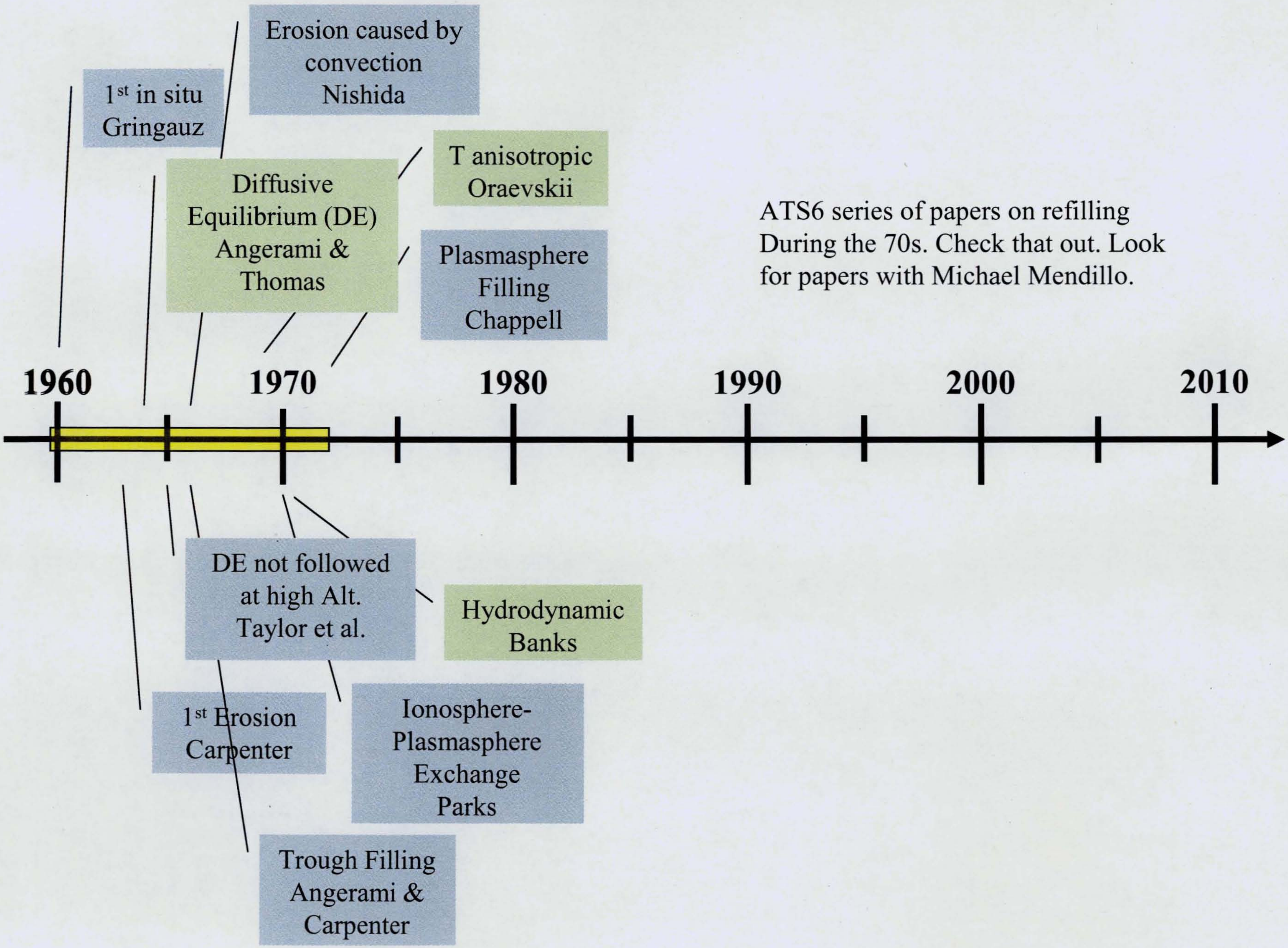
Recovery?



Outflow Physics
p
e-
T⊥, T
uv
g
i,e-
SM Z-axis [RE]
Equatorial Distance [RE]
Z
R
E
X RE
40
30
20
10
0
-10
-20
-30
-40
20
10
5
4
3
2
1
0
0
1
2
3
4
5

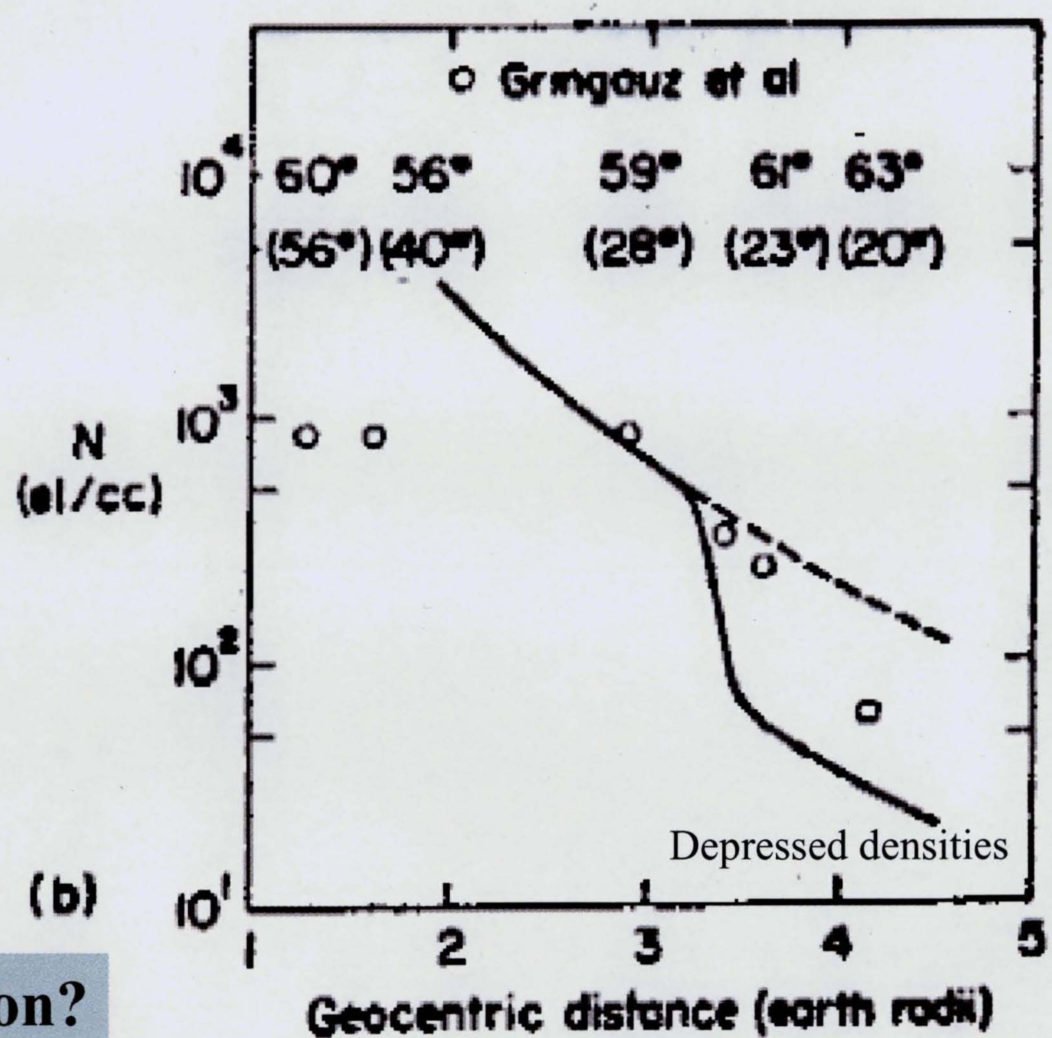
An Abridged History of Plasmaspheric Refilling



ATS6 series of papers on refilling
During the 70s. Check that out. Look
for papers with Michael Mendillo.

The Birth of Refilling
(first there came emptying)

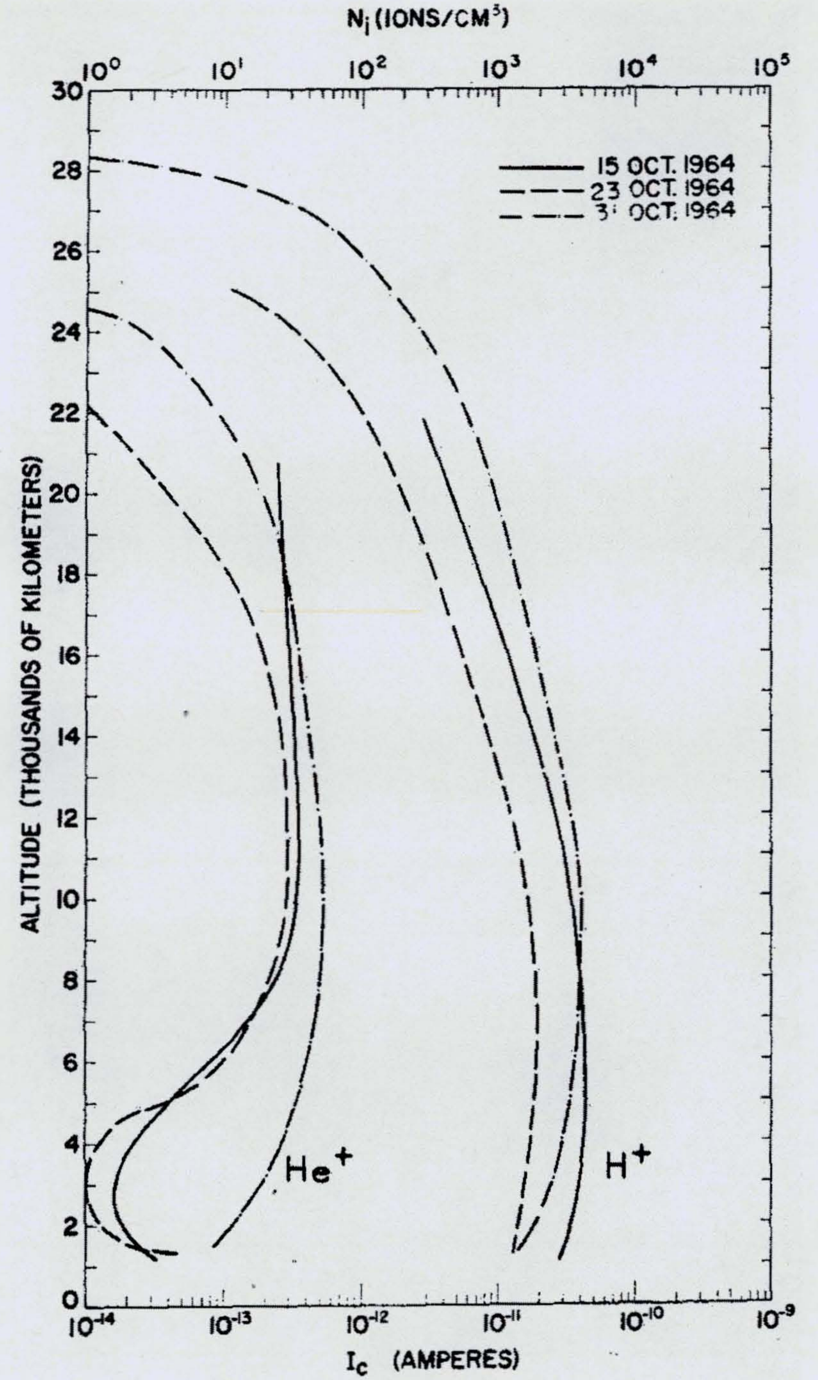
The need to understand plasmaspheric refilling can be traced to the first observations of plasmaspheric erosion. Using charged particle traps on the Soviet lunar vehicles Luna 1 and Luna 2, Gringauz [1959] made the first in situ measurements of thermal ions in the "outermost ionosphere" and using ground whistler measurements Carpenter [1963] discovered an outer boundary to this thermal plasma region found to be sensitive to geomagnetic activity.



Overall loss or redistribution?

How Will Plasma Become Distributed Along Field Lines?

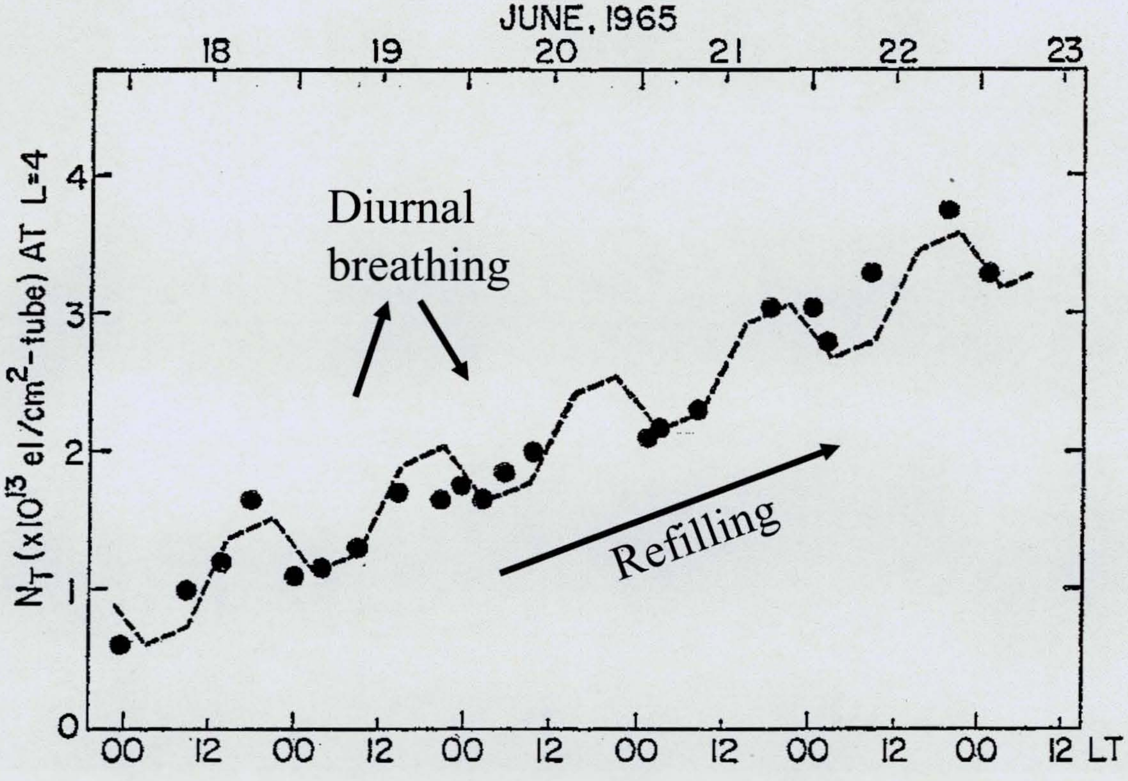
Taylor et al., [1965] concludes their Ogo-A ion measurements are consistent with the models of field aligned density by Johnson [1960], Bates and Patterson [1961], and Angerami and Thomas [1964] at 2000 km, but "exhibit significant departure from these models" at high altitudes up to 30,000 km.



Equatorial densities don't fit the Diffusive Equilibrium model at high altitude.

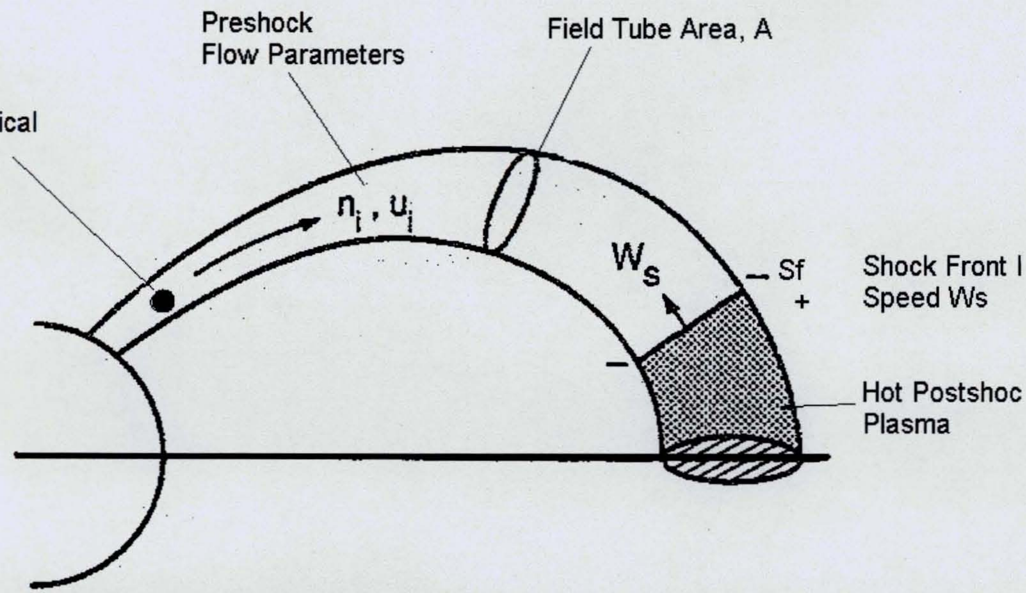
Ionosphere – Plasmasphere Exchange

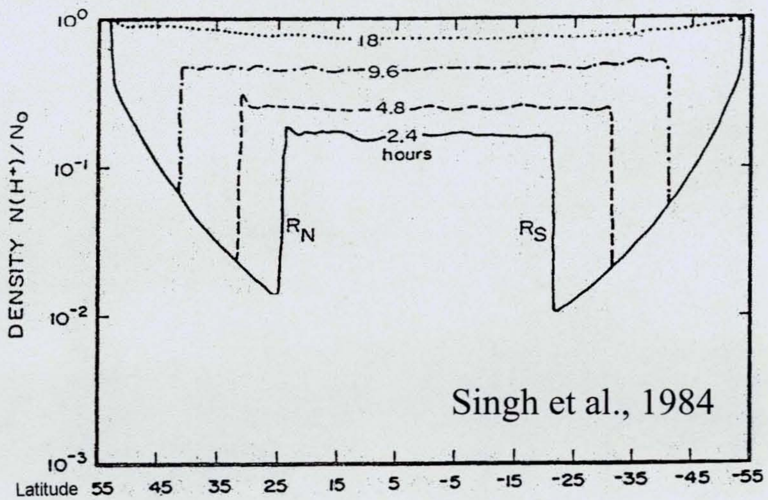
Parks [1970] found that daytime ionospheric outflow was more than enough to allow down flow from the plasmasphere at night to maintain ionospheric densities. Flux tubes 3.5<L<5 take 8-days or more to refill, but probably never get there due to resumed activity. Plasmaspheric recovery comes from ionospheric outflow.



The ionosphere is the source for (slow!) plasmaspheric refilling.

Hydrodynamic Top-Down Refilling

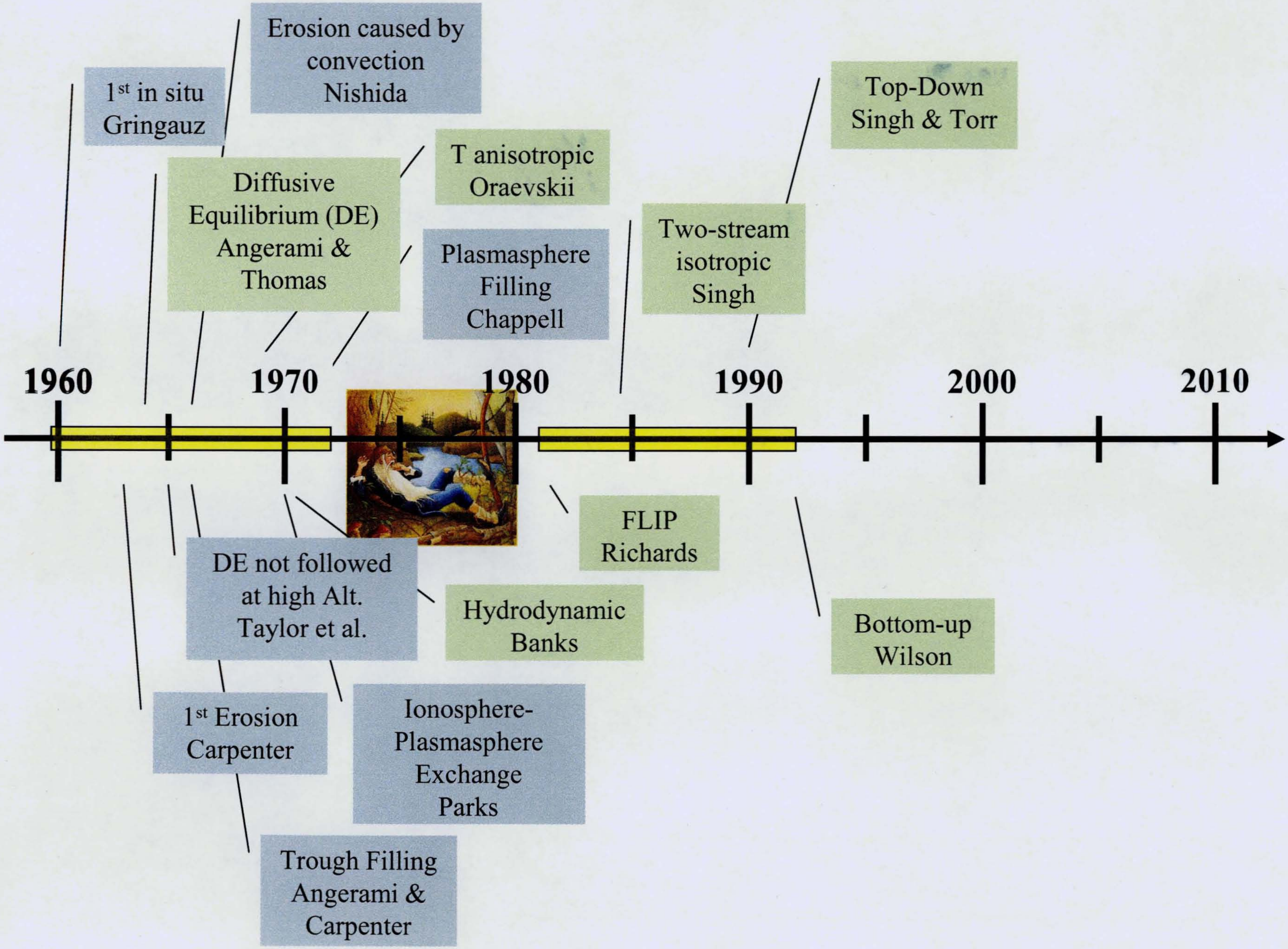




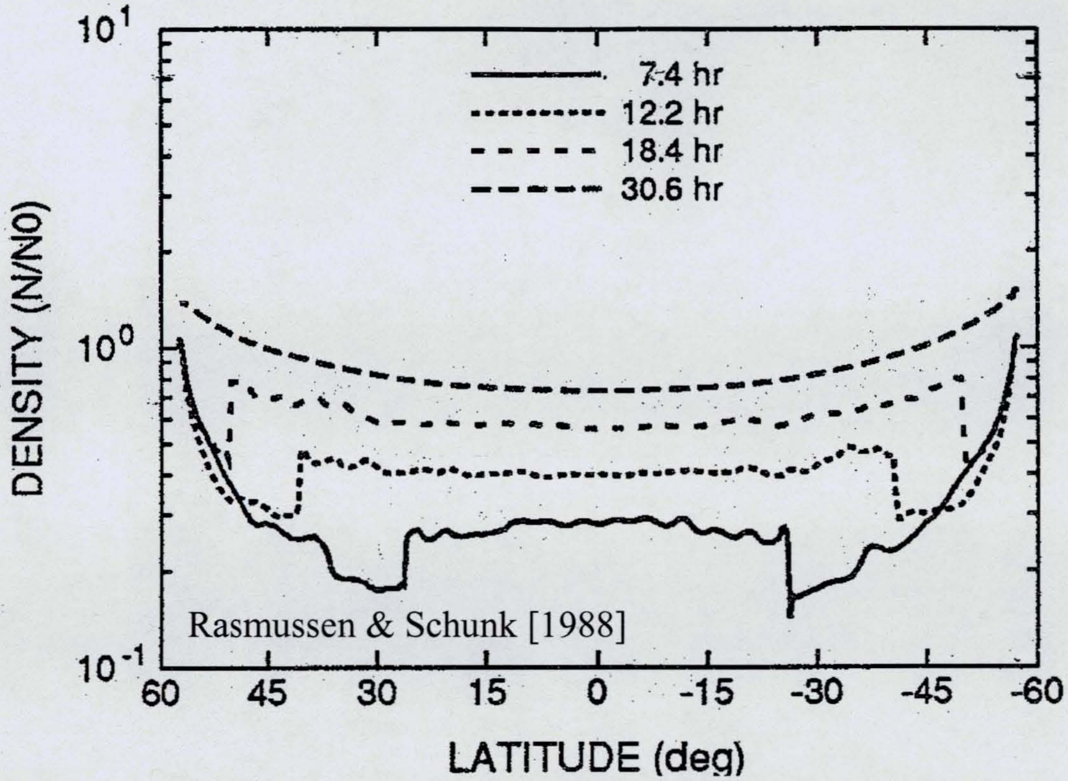
The single-stream hydrodynamic model of Banks [1971] shows the evolution of supersonic streams from the ionosphere during the early stages of refilling to subsonic flows and eventually to a diffusive equilibrium. In the initial phase, supersonic flows from conjugate ionospheres interpenetrate at the equator of the depleted flux tube causing the formation of shocks. The second stage subsonic refilling occurs once the shocks reach the topside of the ionosphere in conjugate hemispheres.

Interacting interhemispheric shocks: Fast two-stage refilling

An Abridged History of Plasmaspheric Refilling



Two-Stream Top-Down

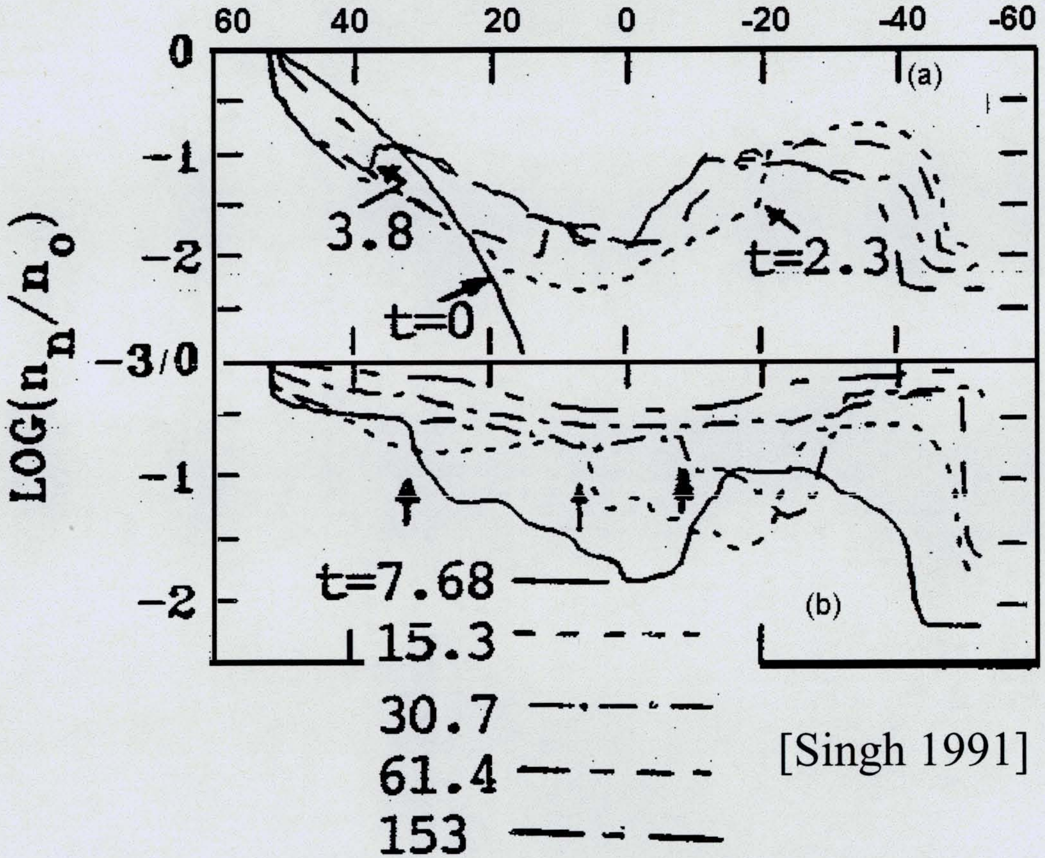


Two-stream models show or do not show shock formation, dependent on the physics of the inter-penetrating interhemispheric streams.

Interacting interhemispheric shocks: Slower refilling

Two Stream Anisotropic Top-Down Refilling

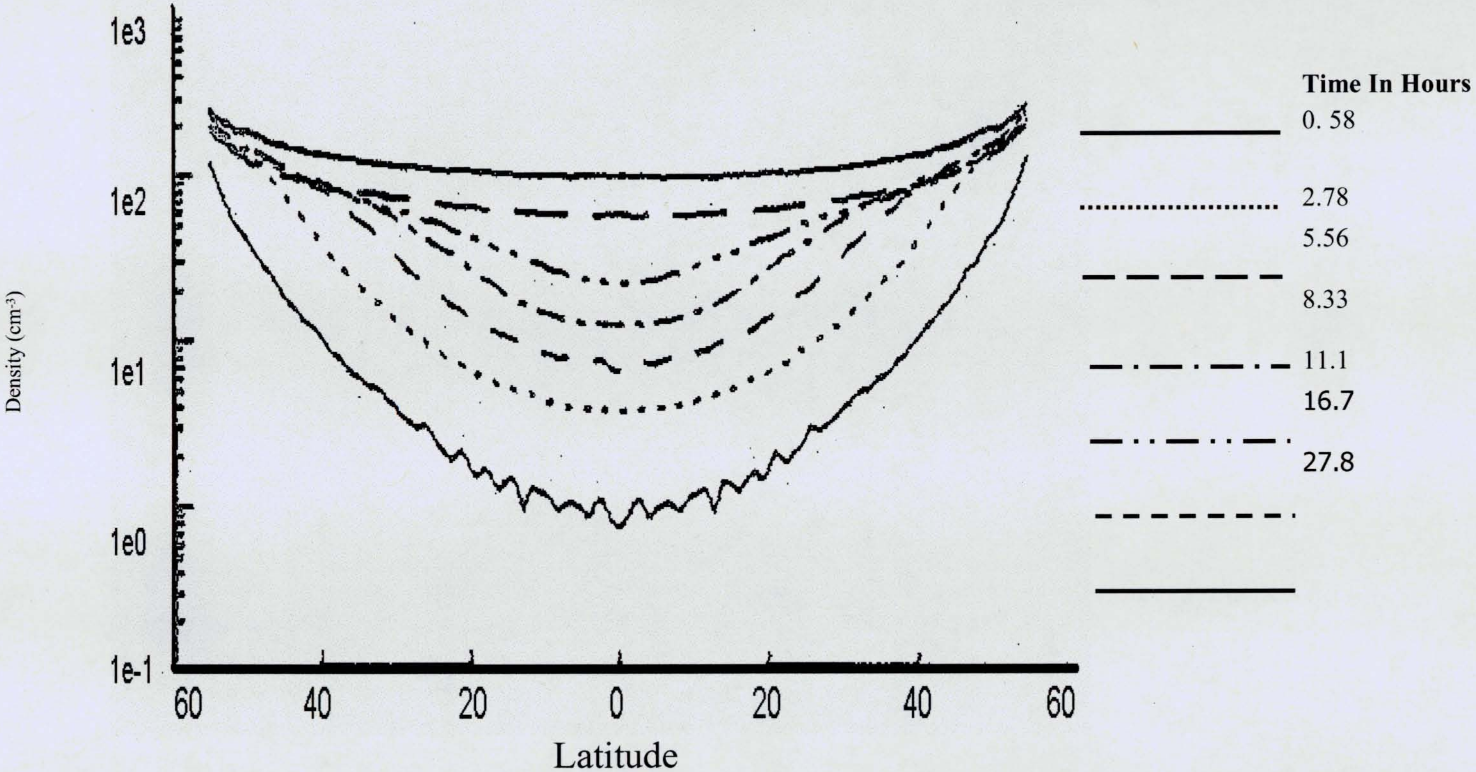
Singh and Torr in 1990 proposed a two stream anisotropic (TAN) model with equatorial ion heating by wave-particle interaction. TAN models show a two-stage refilling. The first stage is characterized by development of supersonic flows in depleted flux tubes, interhemispheric plasma exchange, shock formation in each plasma stream and rapid propagation of the shock first upward to the equator and then downward to the ionosphere. This first stage lasts a short time (~5 hrs) with minimal refilling taking place. When the shocks reach the ionosphere, a quasi-steady distribution results in the flux tube. This allows the second stage of refilling from the ionosphere to occur. These flows are generally subsonic and isotropic in nature.



[Singh 1991]

Non-interacting interhemispheric shocks with slow refilling.

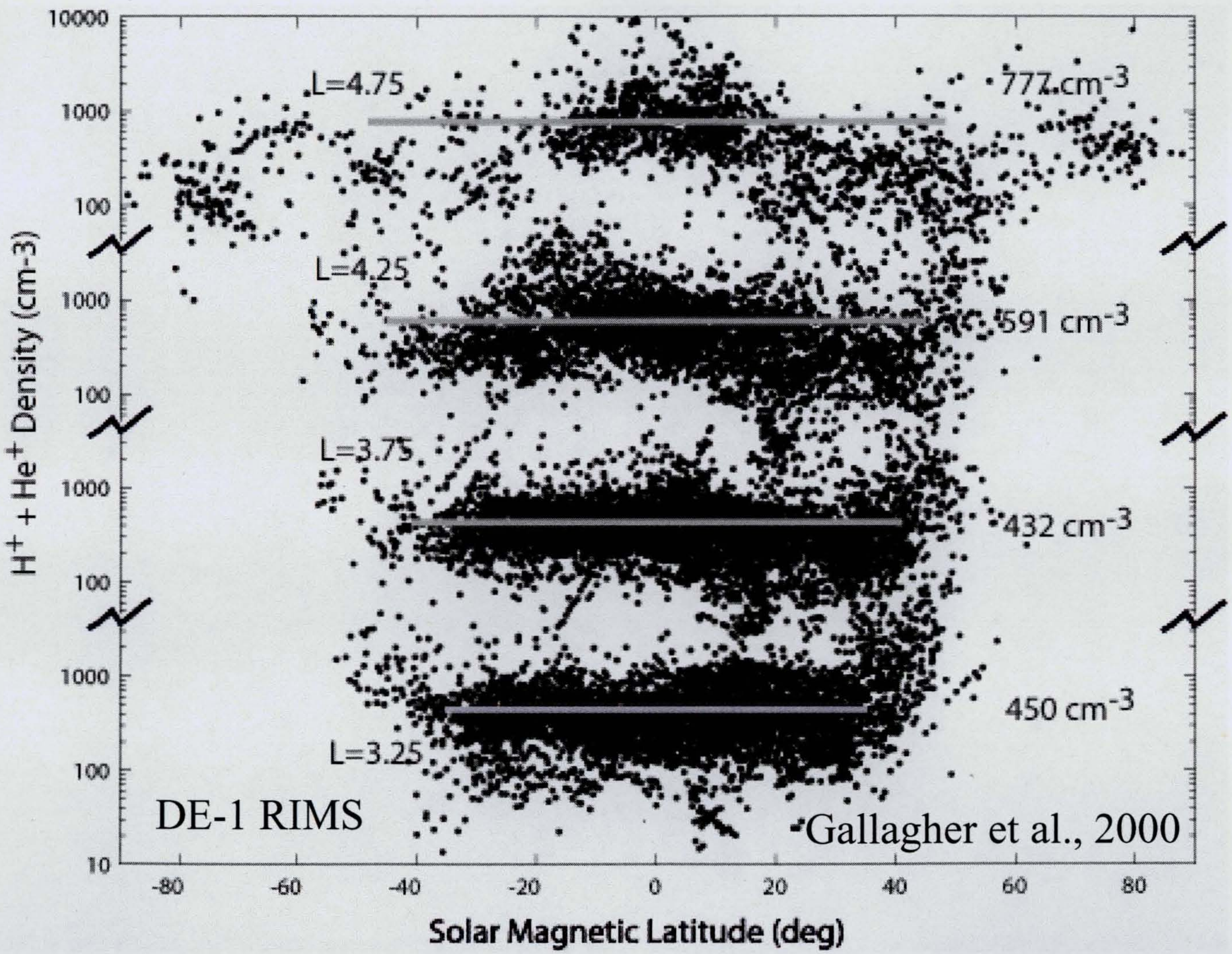
Semi-Kinetic Bottom-Up Refilling



In 1992, Wilson used a semi-kinetic approach that includes Coulomb collisions and wave-particle interactions to model early-time plasmaspheric refilling.

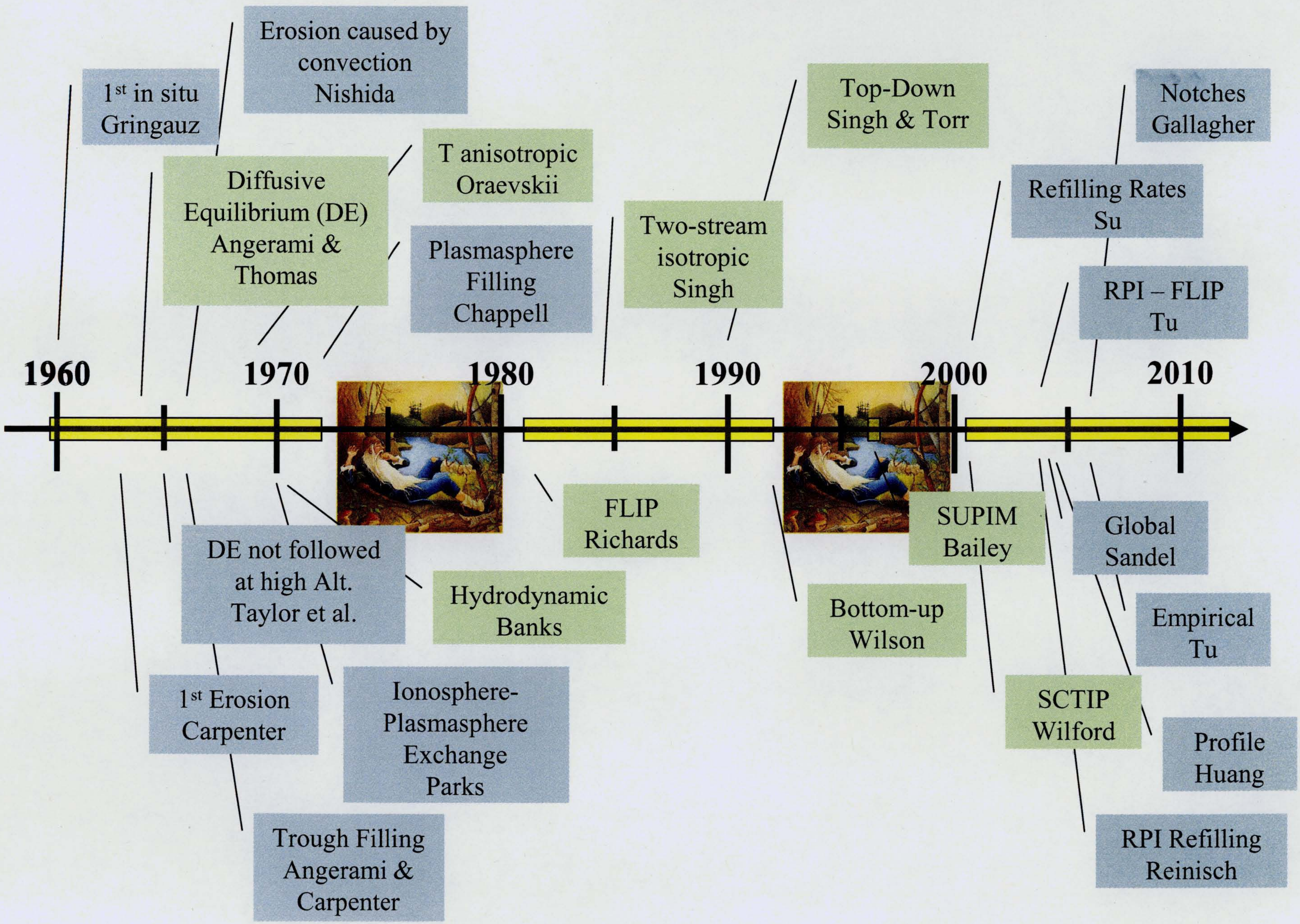
Field aligned profile fills without shock structure.

Density Variation Along the Magnetic Field

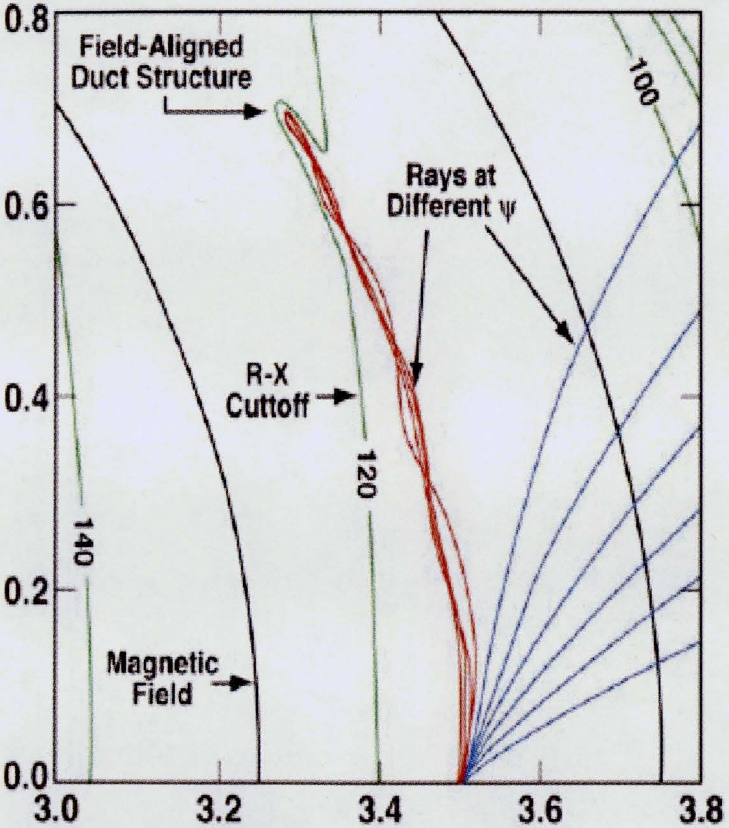


We could only approximate the field-aligned density profile.

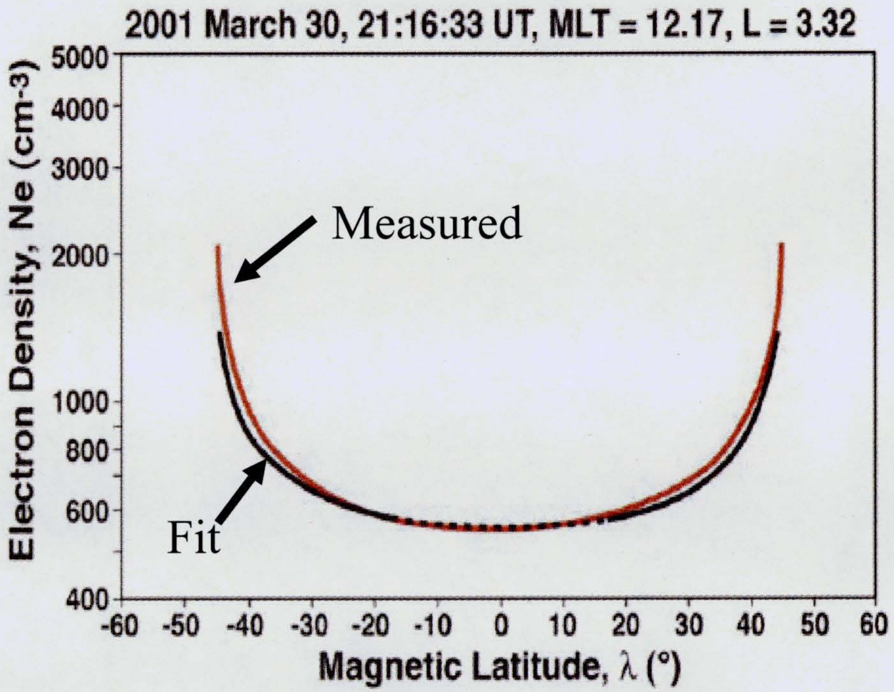
An Abridged History of Plasmaspheric Refilling



True Field-Aligned Densities

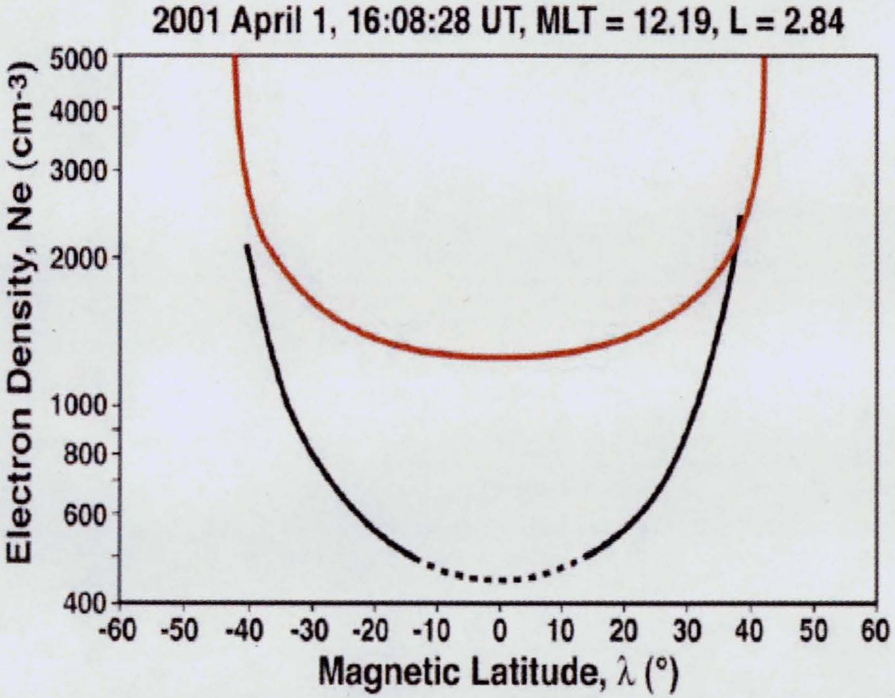


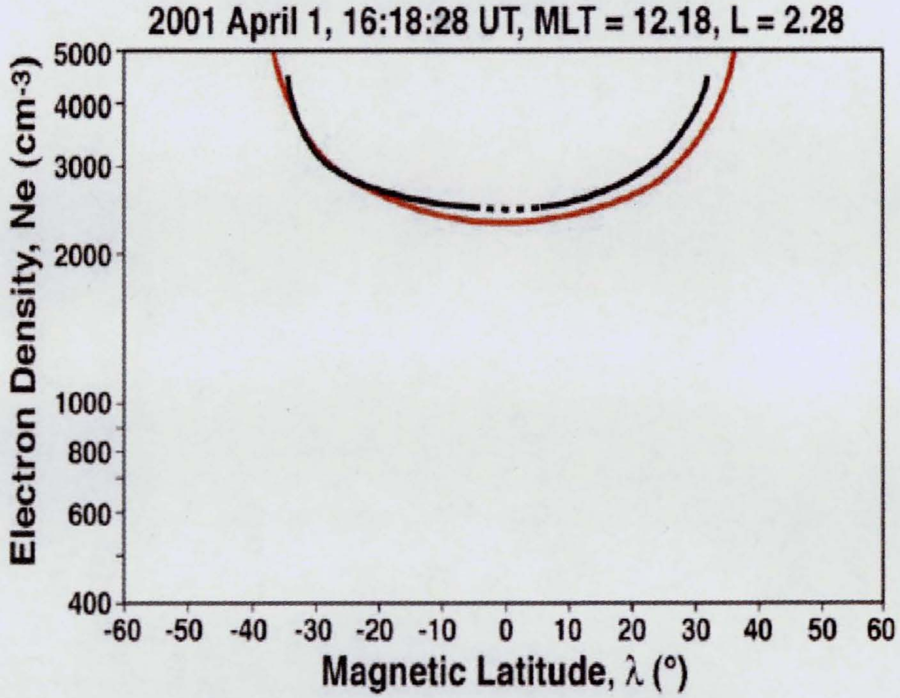
Fung & Green 2005



Physics of plasmaspheric refilling is enabled by RPI
Obvious, but not anticipated!

Plasmasphere Eroded & Filled

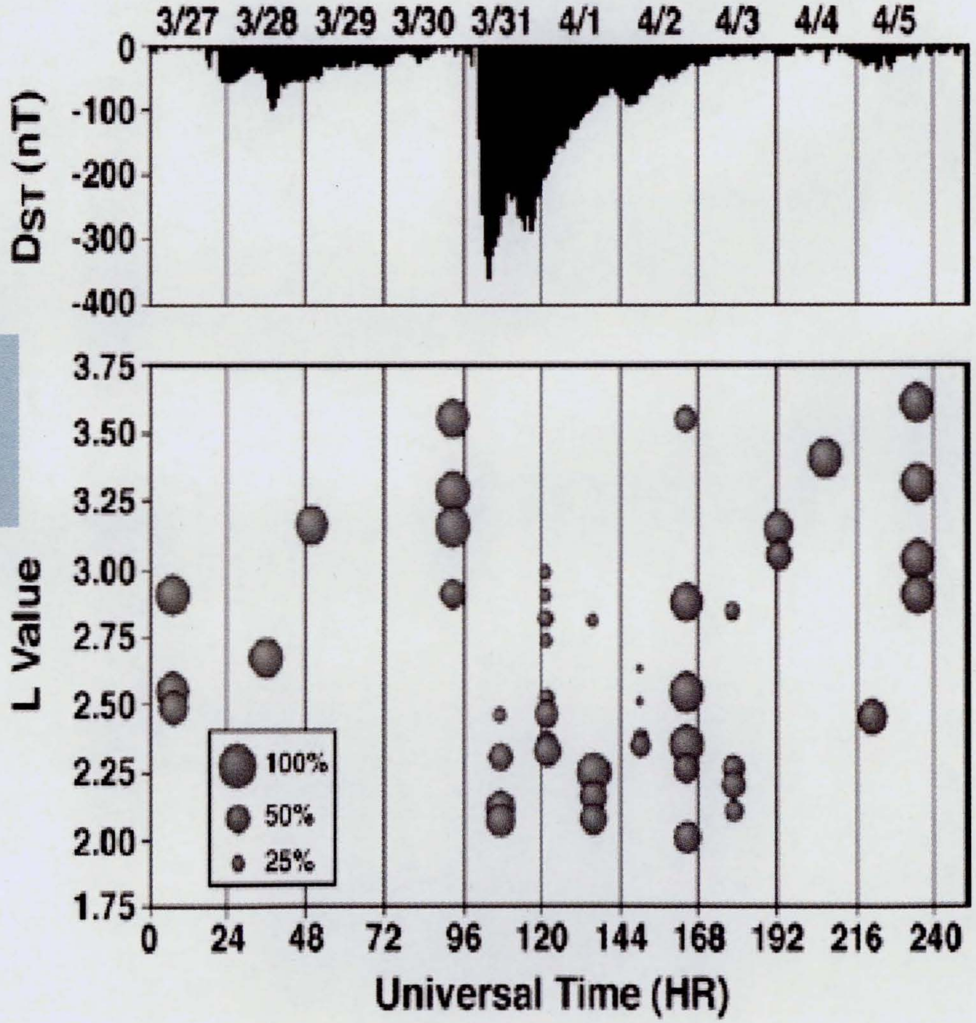




First true measurements of field aligned density profiles

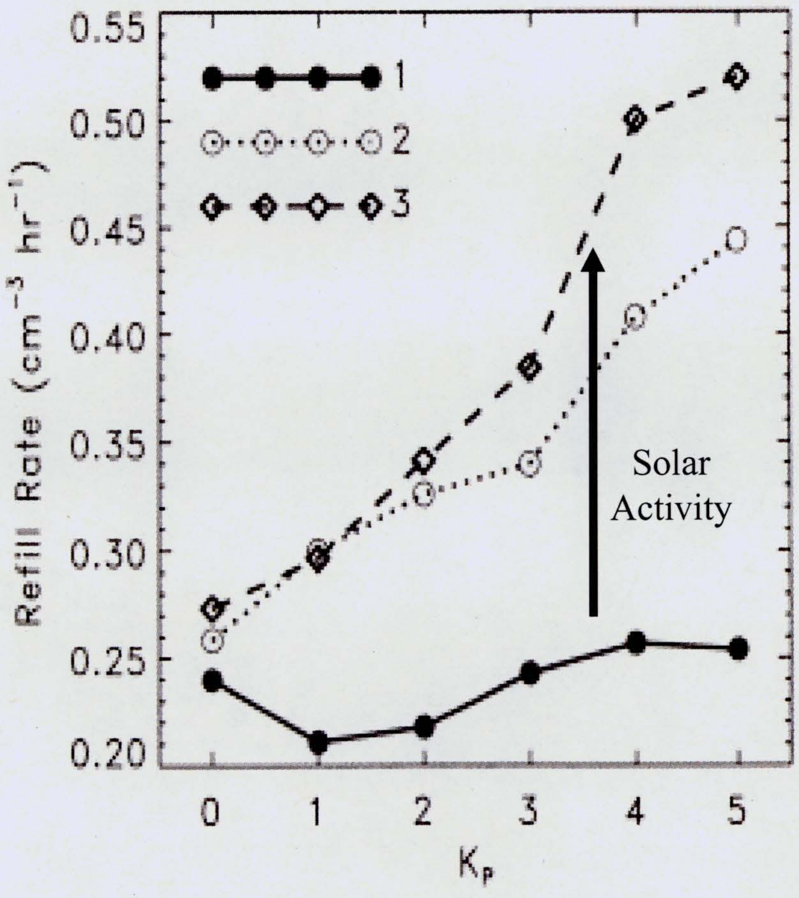
Plasmaspheric Refilling Study Renewed

Reinisch et al., [2003] apply, for the first time, RPI field aligned derived densities to the pattern of refilling.

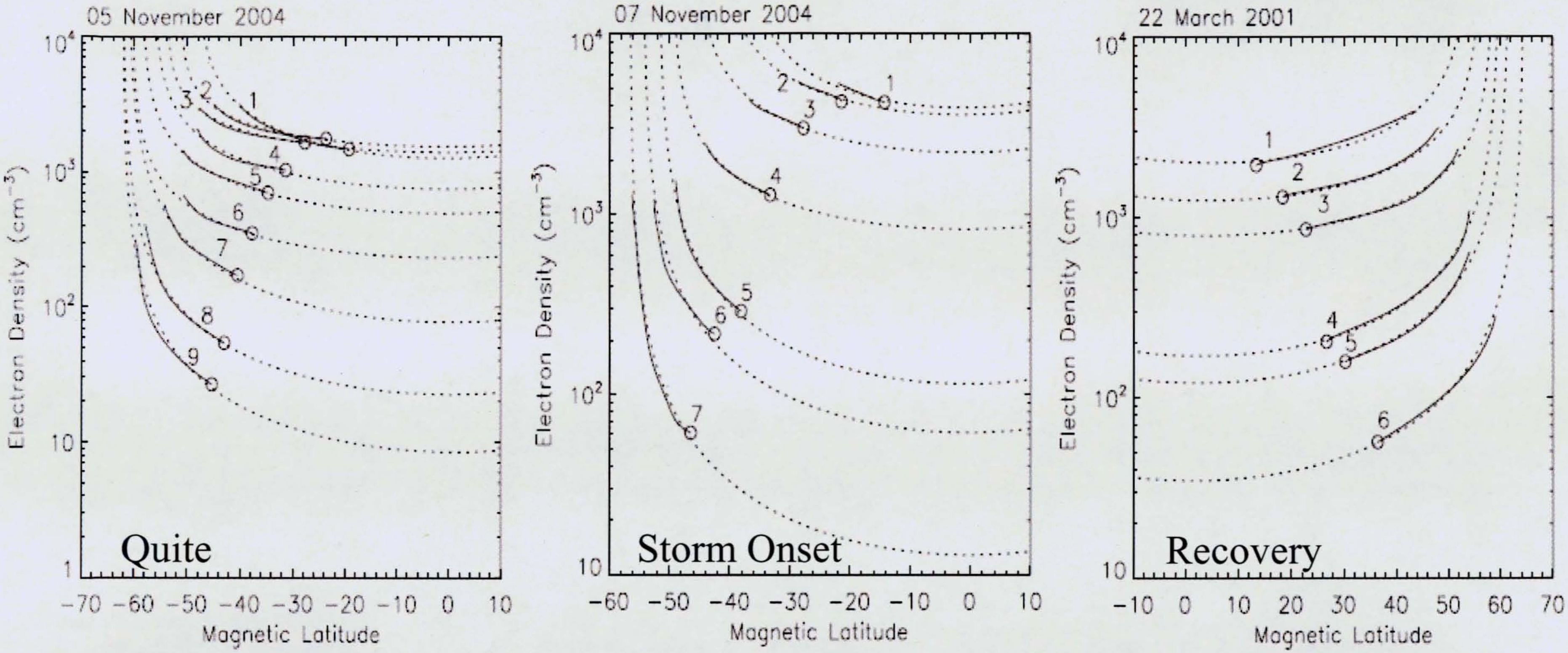


Solar, Season, & Activity Dependent Refilling Rates

Inspired by IMAGE RPI and EUV like many researchers, Su et al., [2001] use geosynchronous observations to find the refilling rate to be non-linear in time and dependent on geomagnetic activity, solar conditions, and seasons.



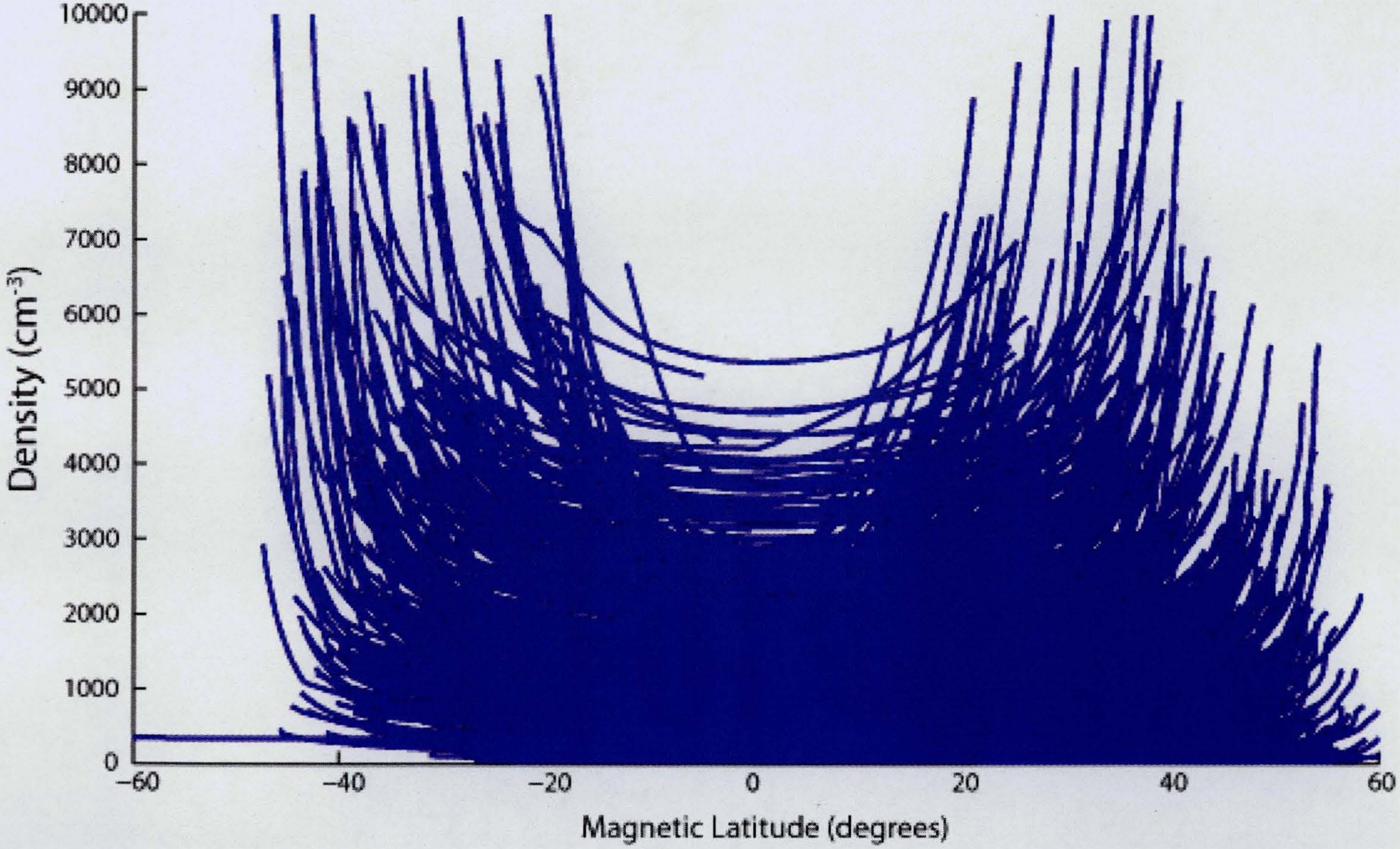
Activity Dependent Field-Aligned Density Gradients



Tu el al., 2006 demonstrate the initial steps for the formation of an empirical model for plasmaspheric and magnetospheric trough field line densities as a function of geomagnetic conditions.

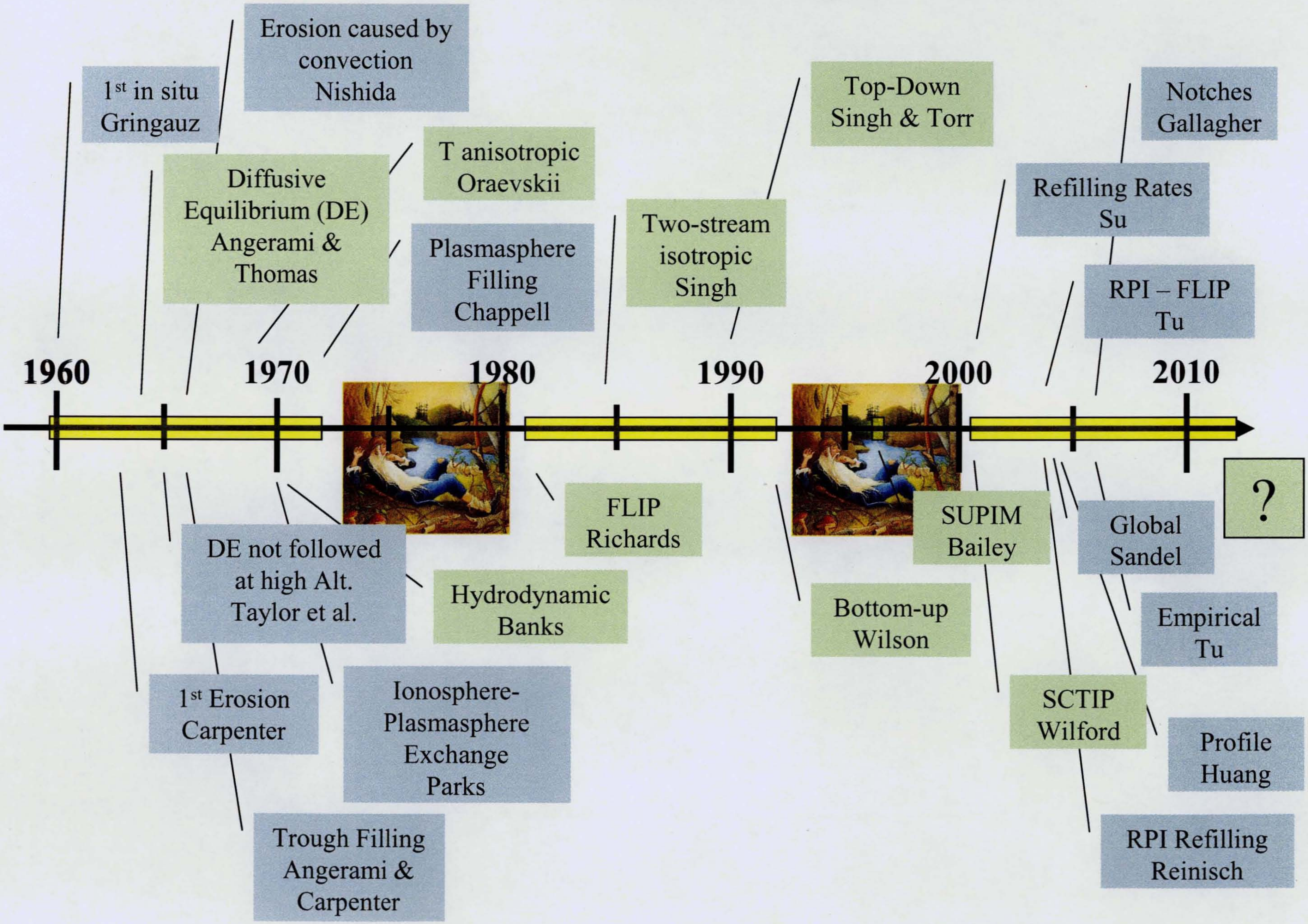
New step toward field-aligned density empirical modeling.

Field-Aligned Densities in 2001

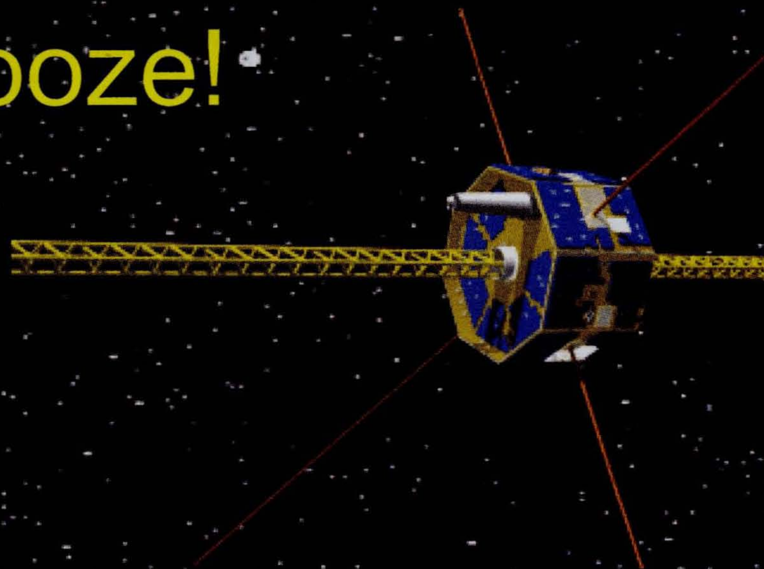


Smith has derived 1556 field-aligned densities profiles from soundings in 2001 as a resource to study plasmaspheric refilling.

An Abridged History of Plasmaspheric Refilling

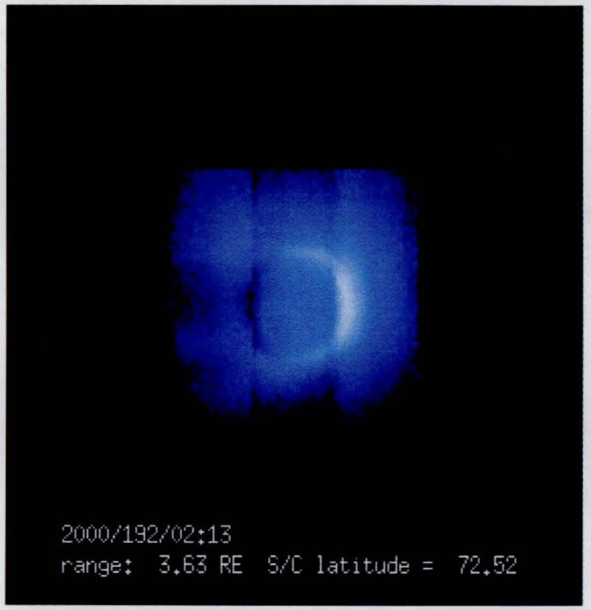


Finally after 47 Years, Rip will soon need to look for a new excuse to snooze!

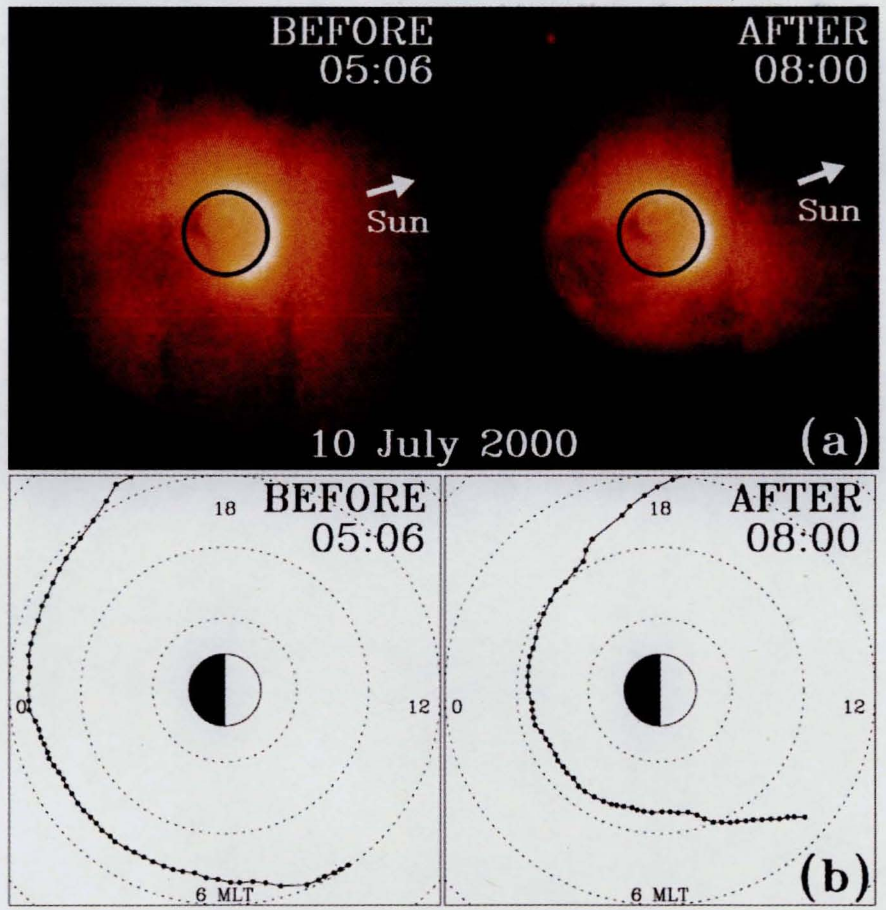


2-D Drift Velocities from the IMAGE EUV Plasmaspheric Imager

D. Gallagher and M. Adrian



Will focus discussion of the technique and initial results on one plasmaspheric erosion time period



Goldstein et al., GRL, 2004

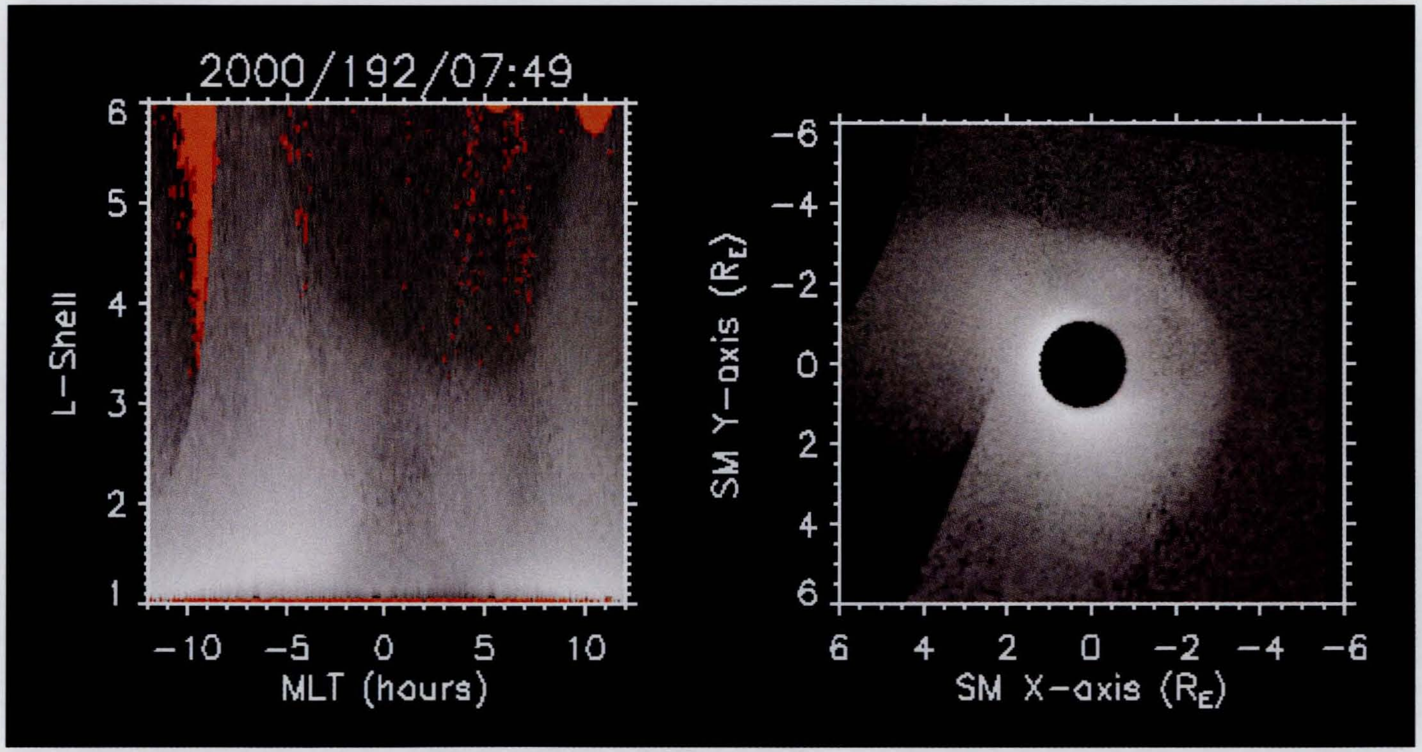
Regional Plasmaspheric Drift

Objective:

Use all available intensity structure in a series of EUV images to quantify movement of image elements within the field of view to fulfill promise of obtaining 2D E-fields.

Preparation:

Perform the analysis using image observations projected into the magnetic equatorial plane such that image products can be directly compared. That is done here using the pseudo-density calculation.



To Compute 2D Plasmaspheric Drift

Techniques: Optical Flow and Cross-Correlation

Optical Flow:

Optical flow constraint equation $$-\frac{\partial I}{\partial t} = \frac{\partial I}{\partial x}\left(\frac{\partial x}{\partial t}\right) + \frac{\partial I}{\partial y}\left(\frac{\partial y}{\partial t}\right)$$

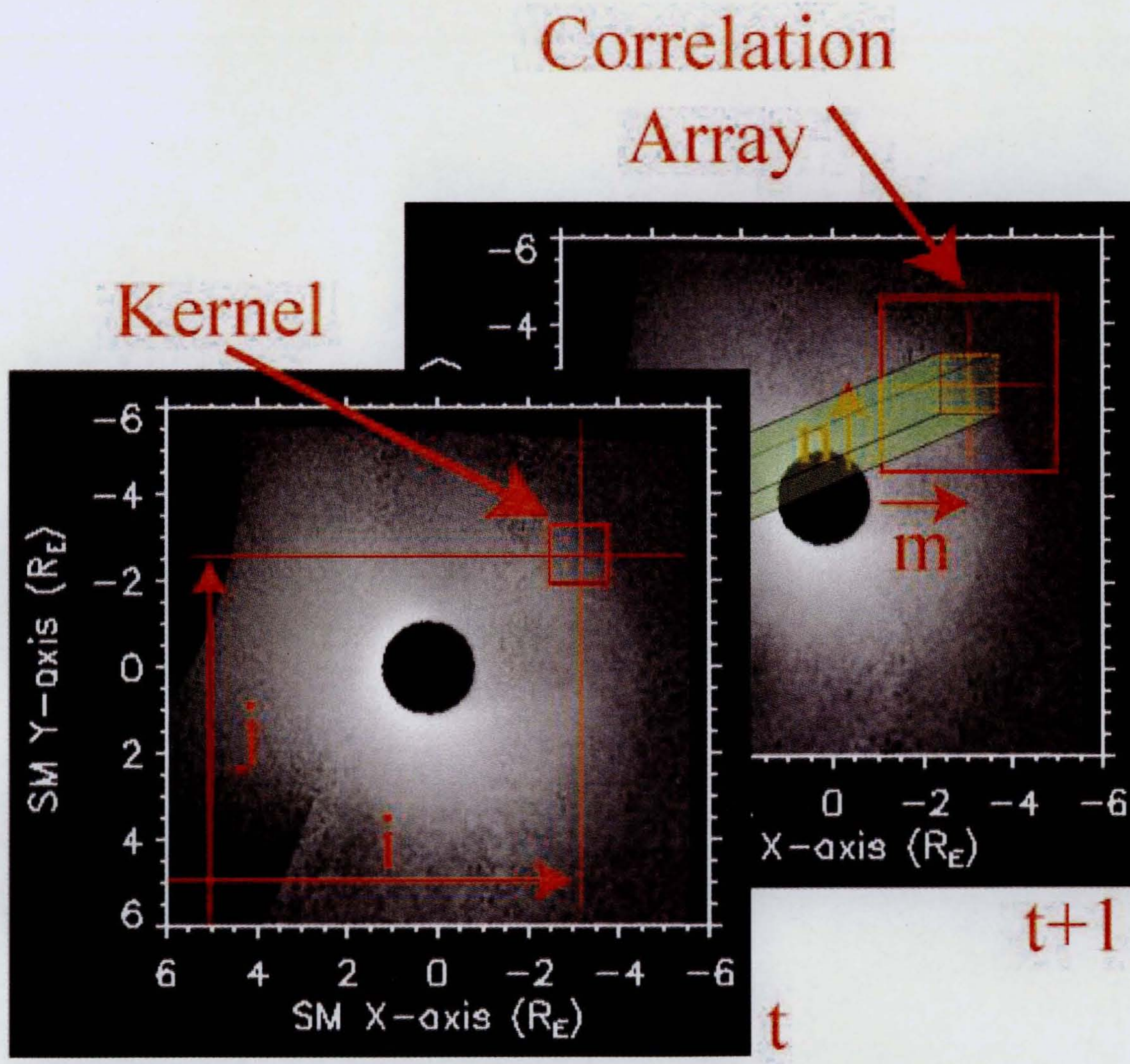
Tried by Christophe Bernard (École Polytechnique in France) without useful results so far. IDL code available at
http://csrsrv1.fynu.ucl.ac.be/csr_web/data/

Cross-Correlation:

With this technique image elements are directly compared for correspondence.

Selected elements from one image or kernels are swept across portions of a second image looking for the best match.

The shifted position of the best match defines the motion of that image element.



$$CrossCorrelationArray(i,j)_{m,n} = \frac{\displaystyle\sum_{kernel\,@(m,n)} \left({(KernalDensity - SubarrayDensity)}\big/{KernalDensity} \right)^2}{\#elements}$$

Here's the Challenge

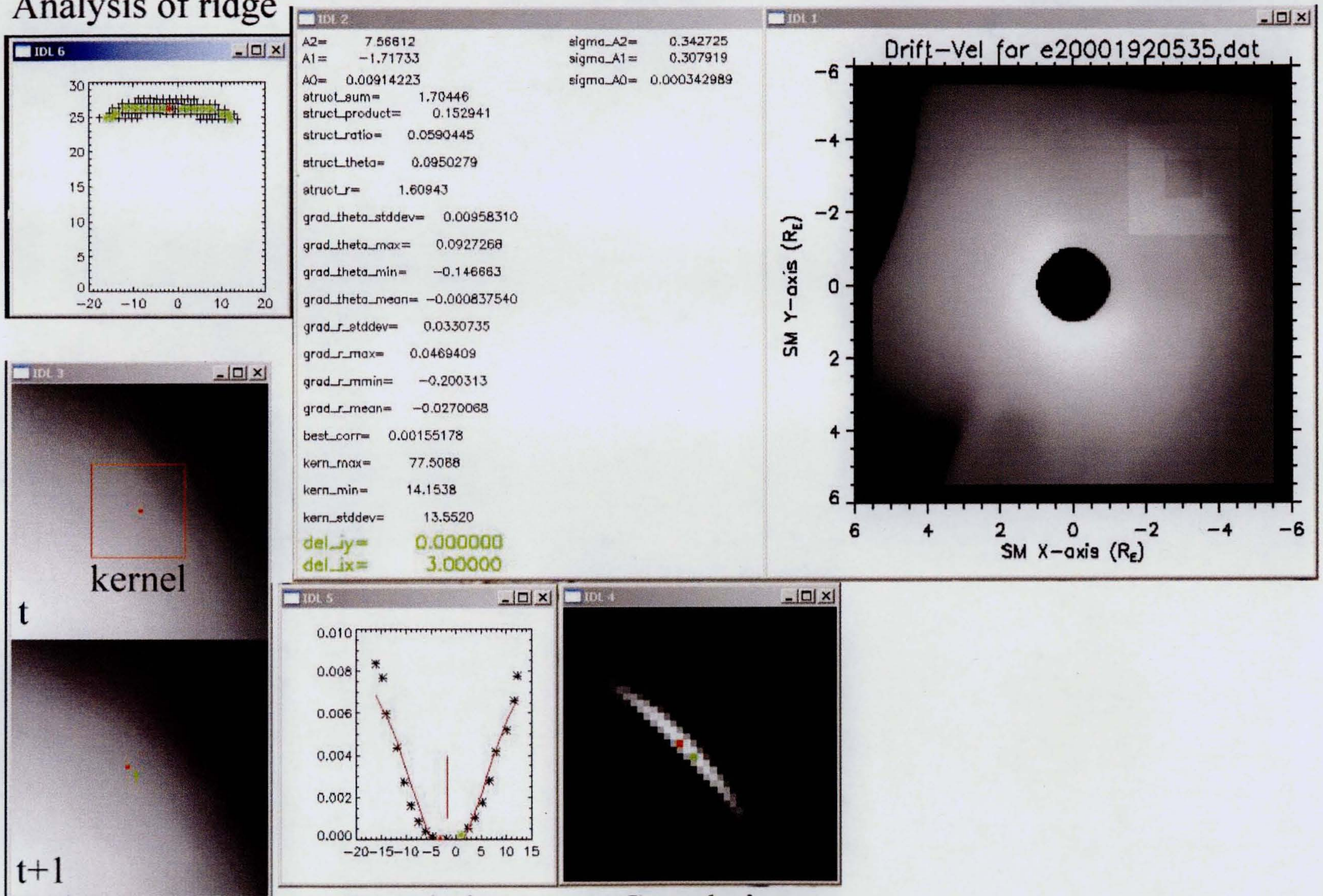
- Plasmapause
- Noise
- Shadow
- Ionosphere
- Other features?

Cross-Correlation Development Tool

Analysis of ridge

Candidate selection criteria

Image for region selection



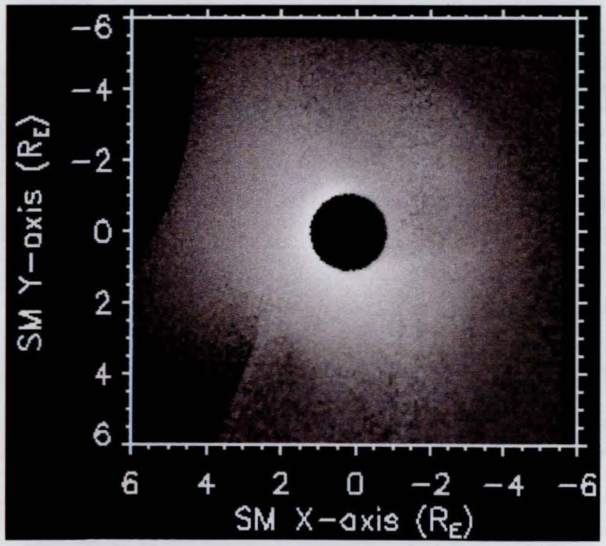
Subarrays being compared

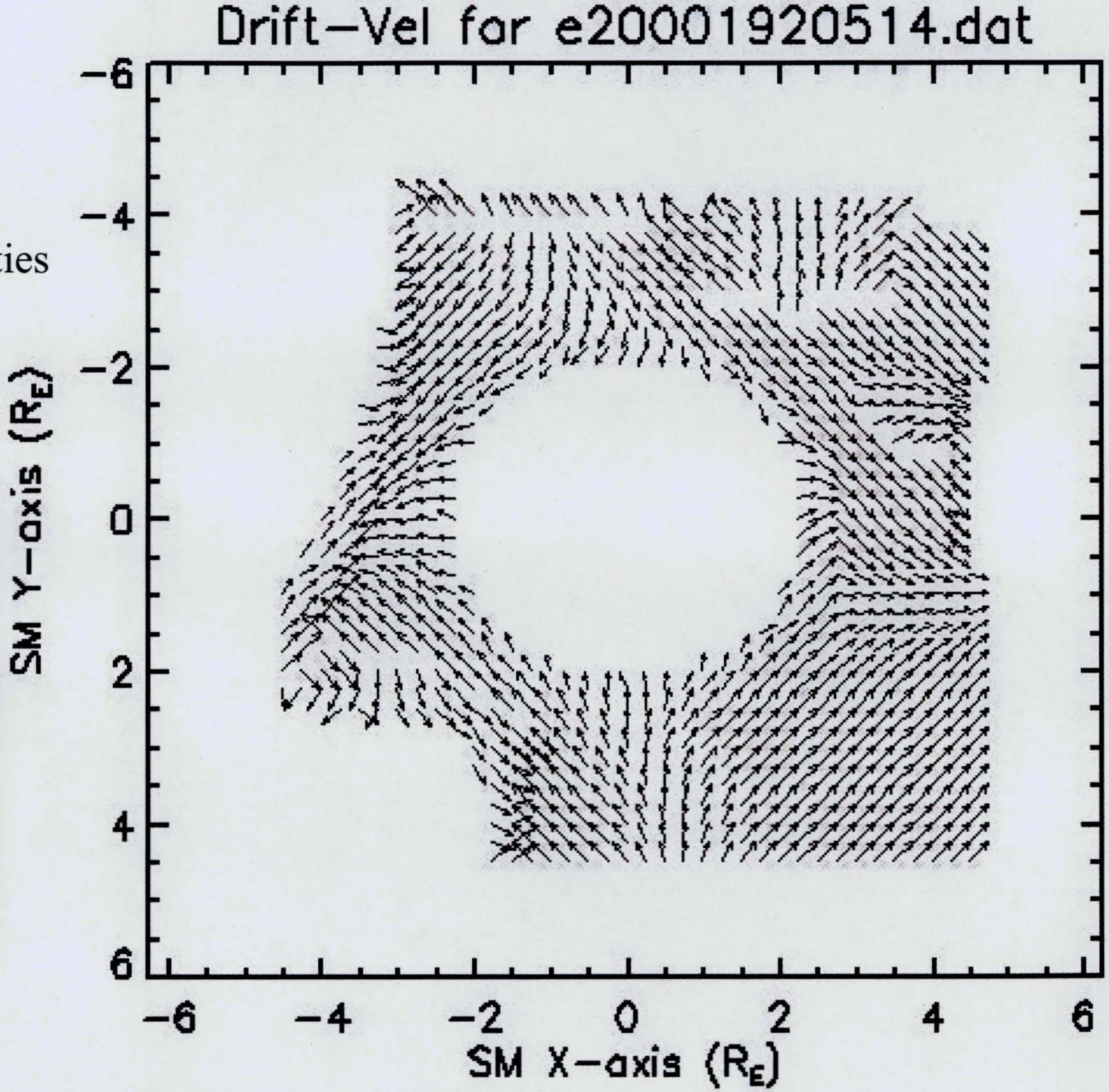
Correlation along ridge

Correlation array

Noise Dominates –

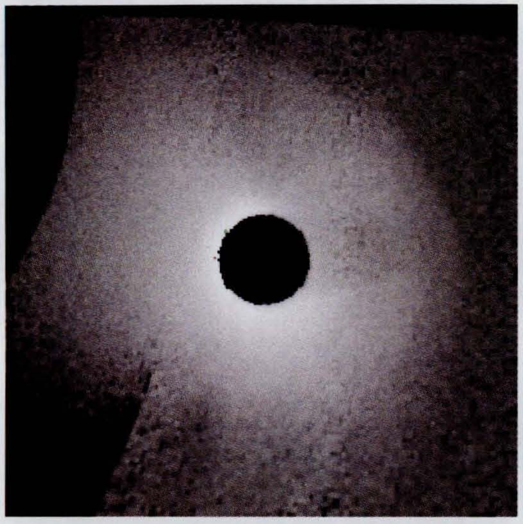
Without treatment, noise dominates derived flow velocities





A Few Noise Removal Techniques Tried

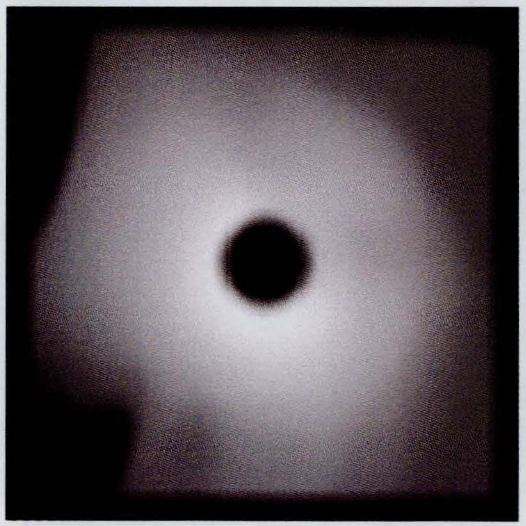
Original



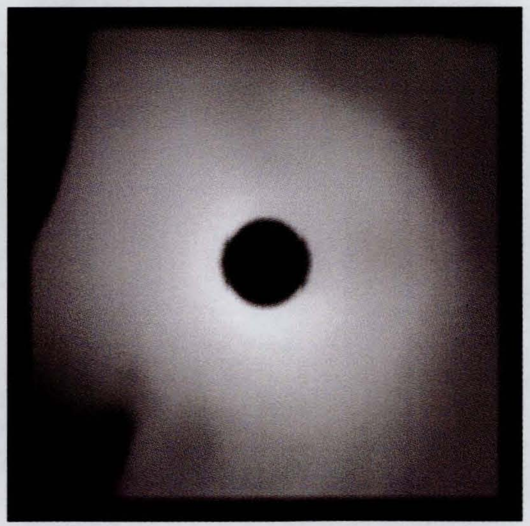
Median - 11

Median - 21

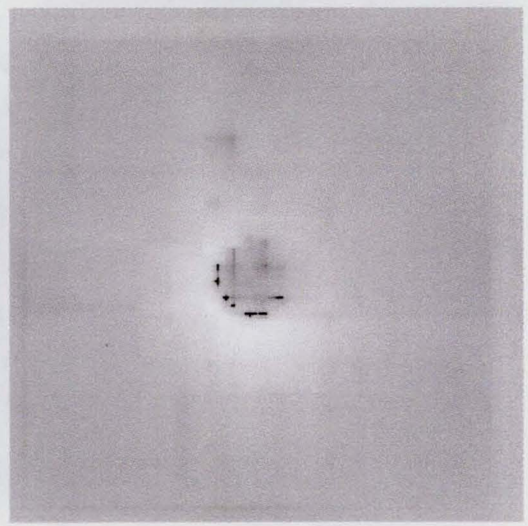
Lee Filter



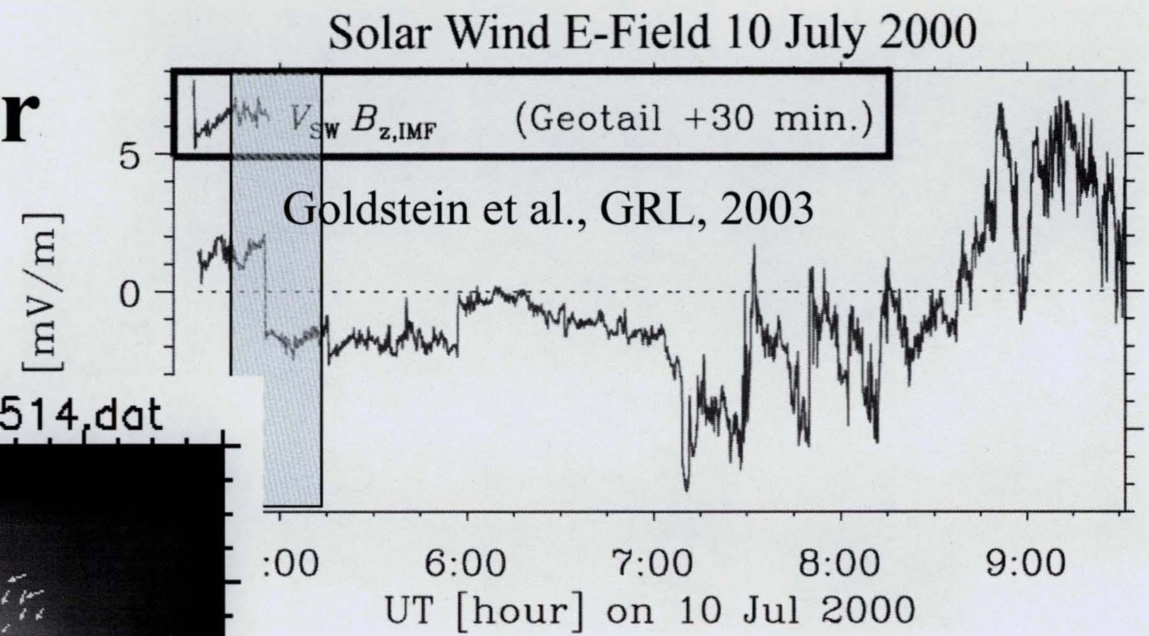
Box Car Smooth - 5

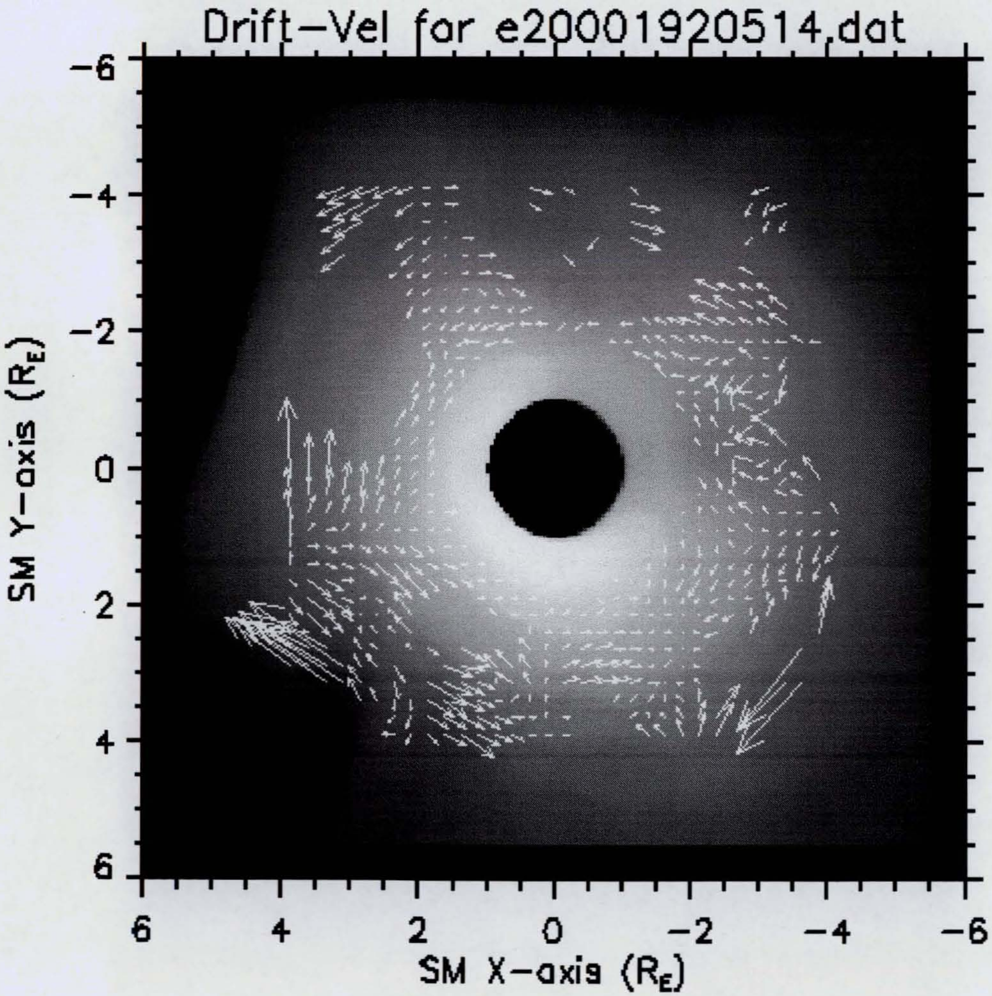


Wavelet Symlet



Initial Results for July 10, 2000

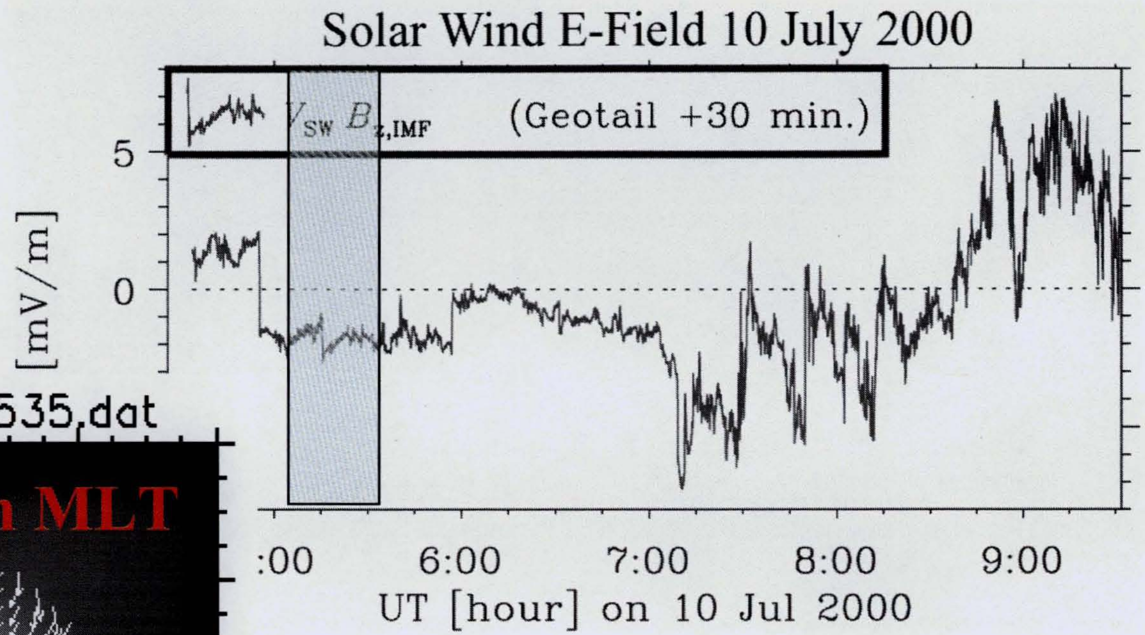




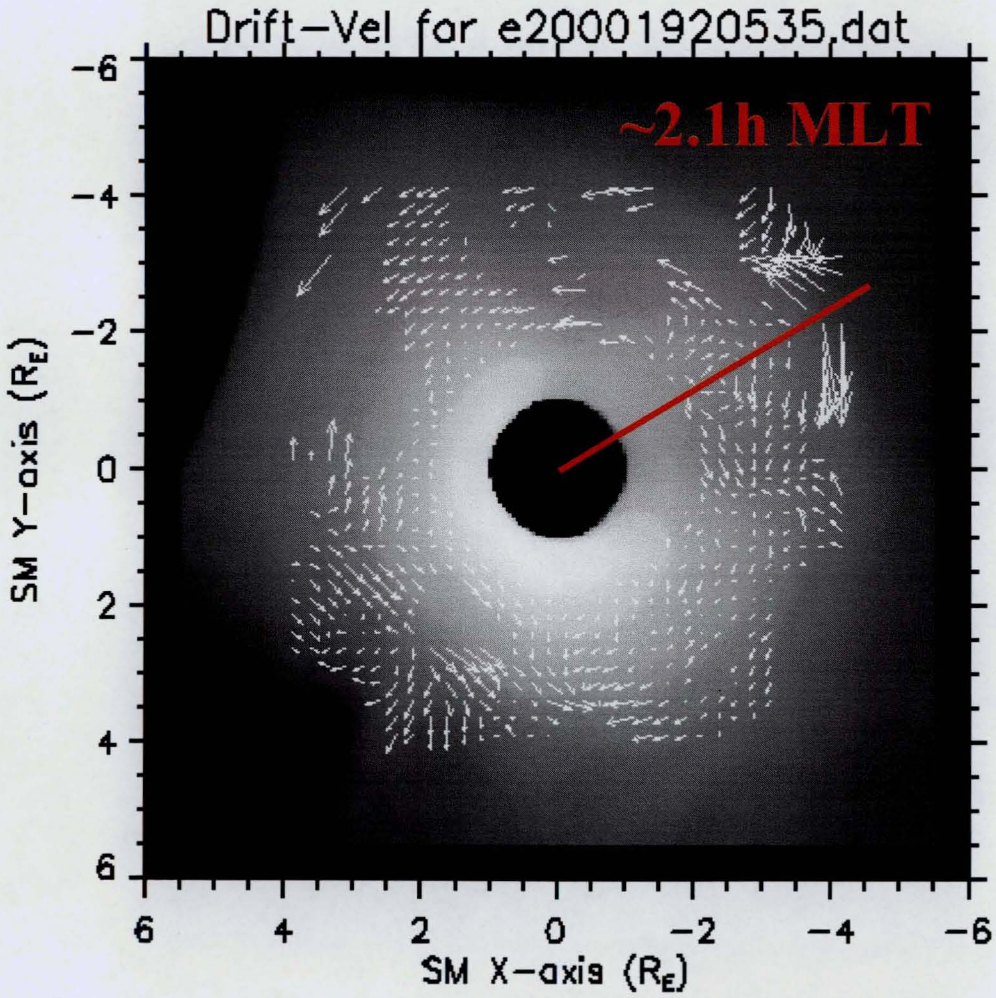
Analysis performed between image products separated by 20 minutes

Noise removed from linear pseudo-density.

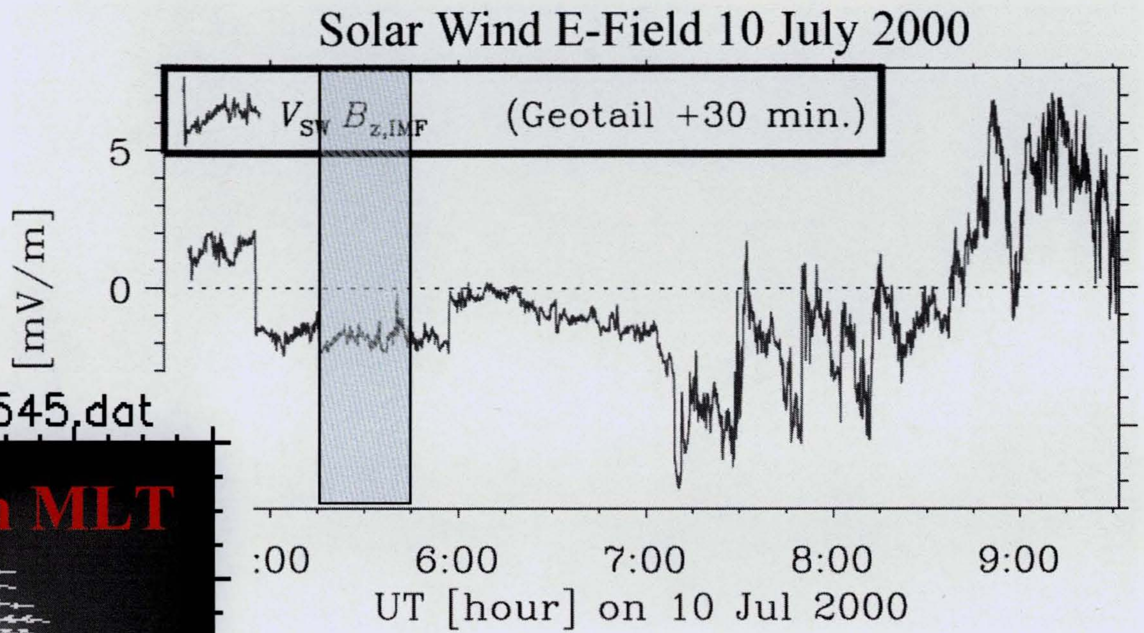
Correlation performed on linear pseudo-density.

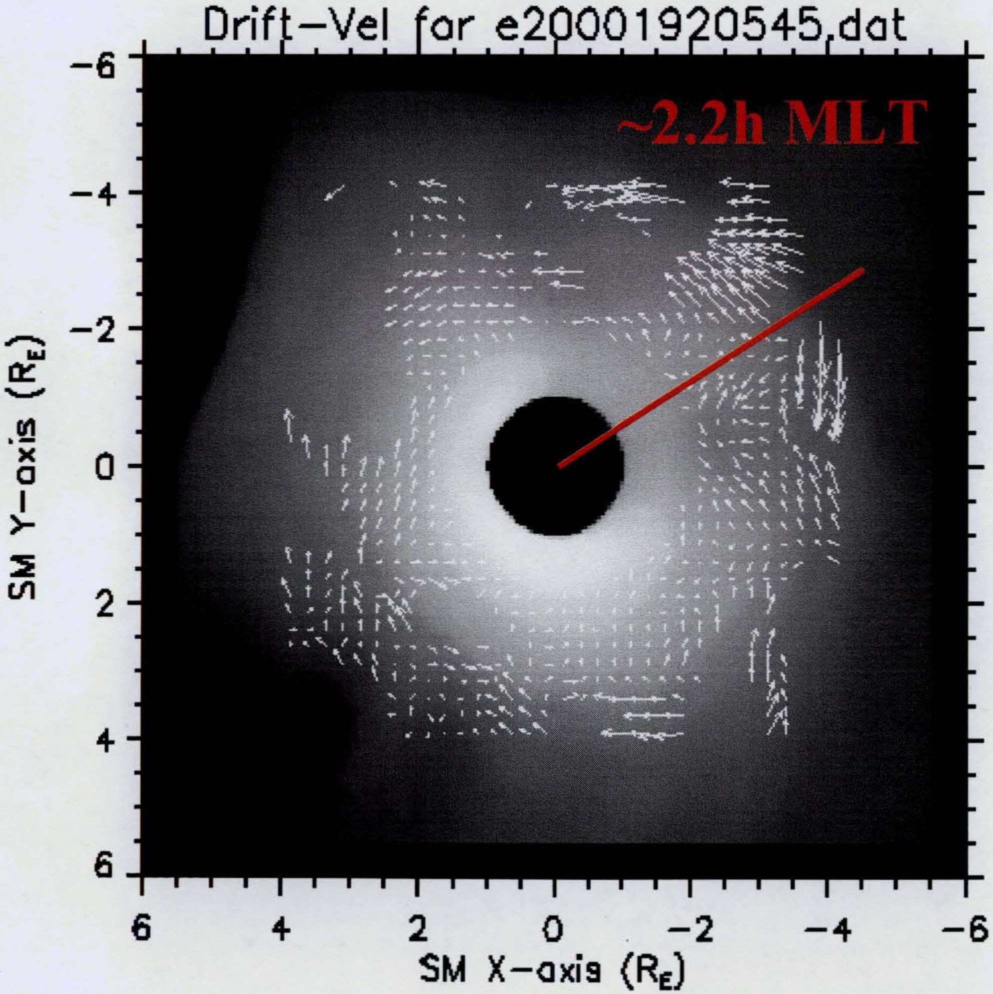


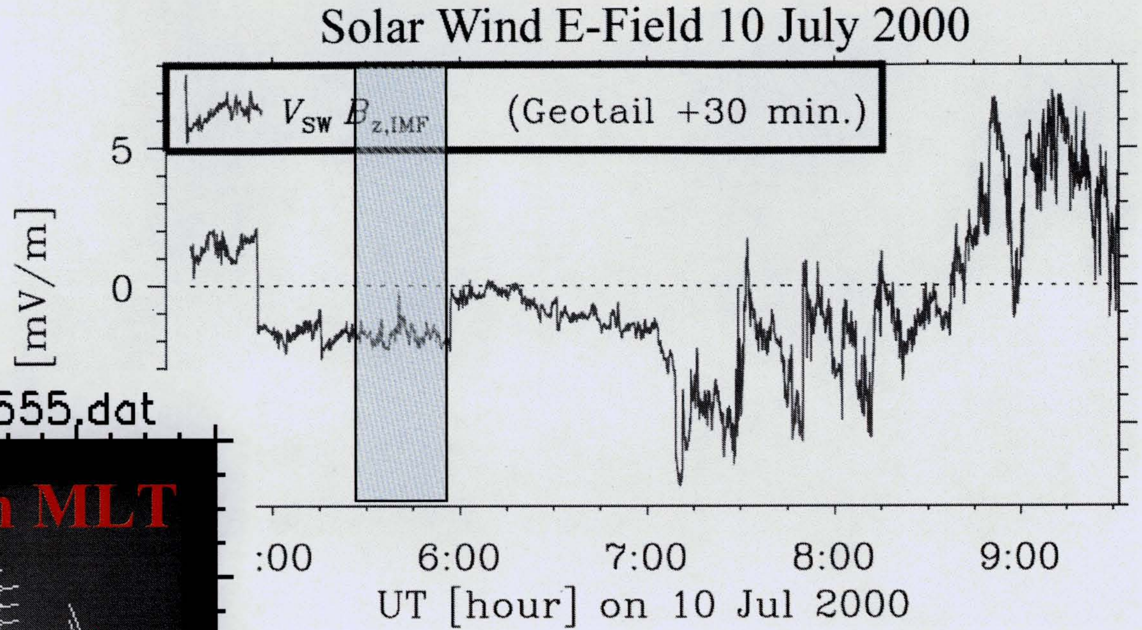
Solar Wind E-Field 10 July 2000
V_SW B_z,IMF
(Geotail +30 min.)
[mV/m]
5
0
:00
6:00
7:00
8:00
9:00
UT [hour] on 10 Jul 2000

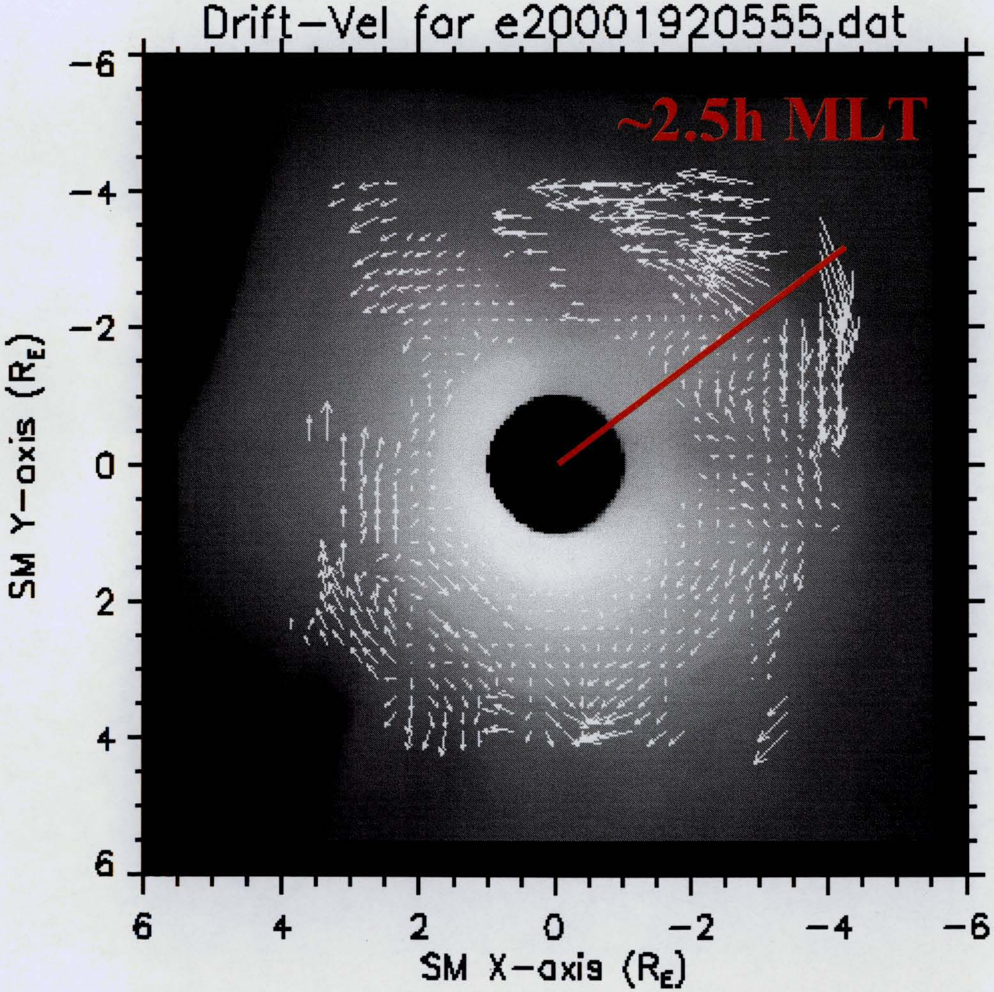


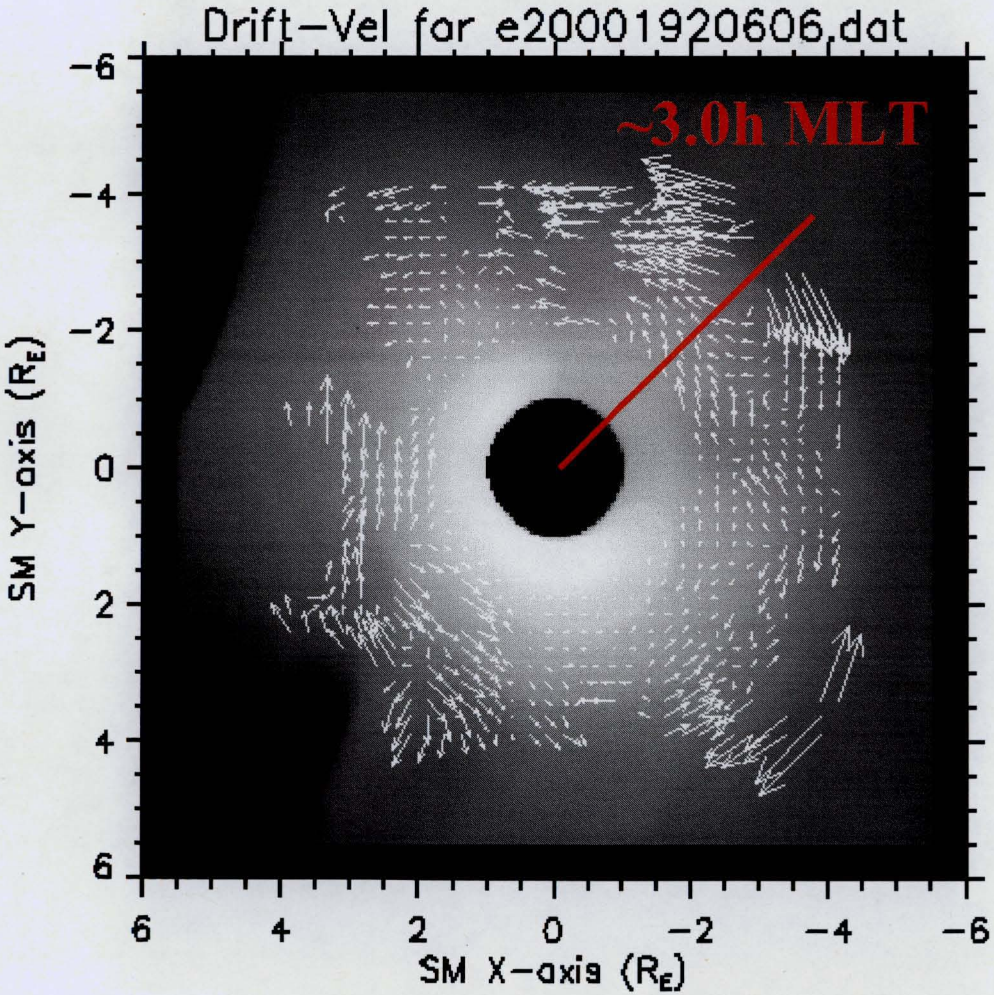
Drift-Vel for e20001920535.dat
~2.1h MLT
SM Y-axis (R_E)
SM X-axis (R_E)
-6
-4
-2
0
2
4
6


Solar Wind E-Field 10 July 2000
V_{SW} $B_{z,IMF}$ (Geotail +30 min.)
[mV/m]
5
0
:00
6:00
7:00
8:00
9:00
UT [hour] on 10 Jul 2000

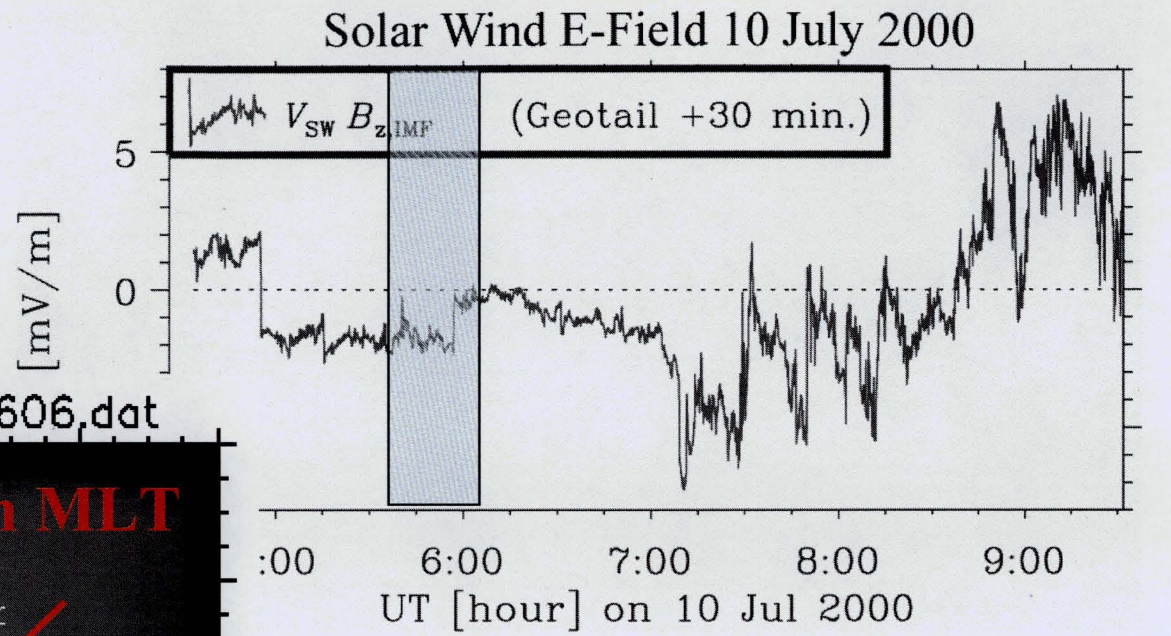

Drift-Vel for e20001920545.dat
~2.2h MLT
SM Y-axis (R_E)
SM X-axis (R_E)
-6
-4
-2
0
2
4
6


Solar Wind E-Field 10 July 2000
$V_{SW} B_{z,IMF}$ (Geotail +30 min.)
[mV/m]
5
0
:00
6:00
7:00
8:00
9:00
UT [hour] on 10 Jul 2000

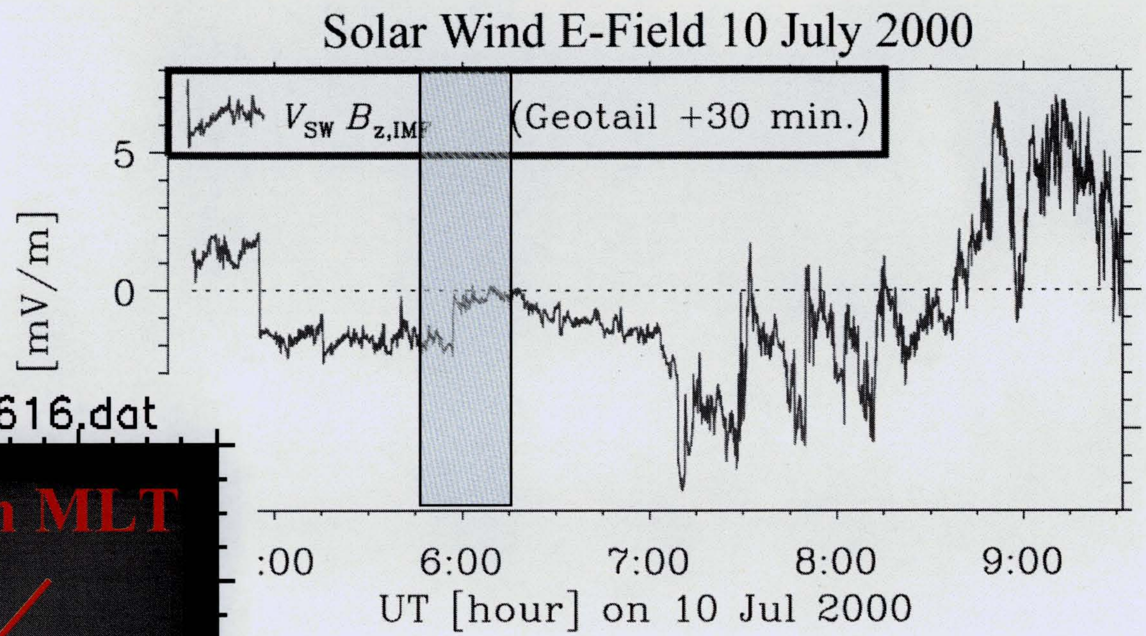

Drift–Vel for e20001920555.dat
~2.5h MLT
SM Y–axis (R_E)
SM X–axis (R_E)
–6
–4
–2
0
2
4
6



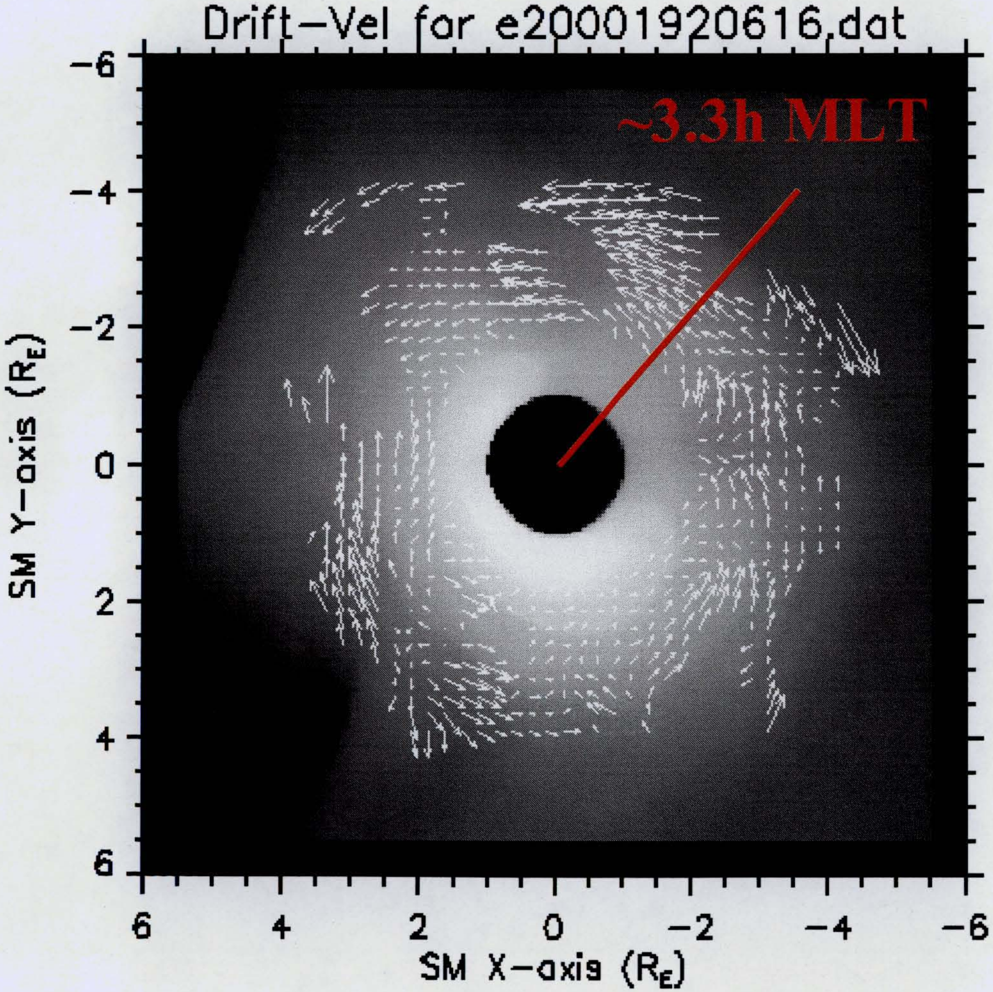
Drift-Vel for e20001920606.dat
~3.0h MLT
SM Y-axis (R$_E$)
SM X-axis (R$_E$)



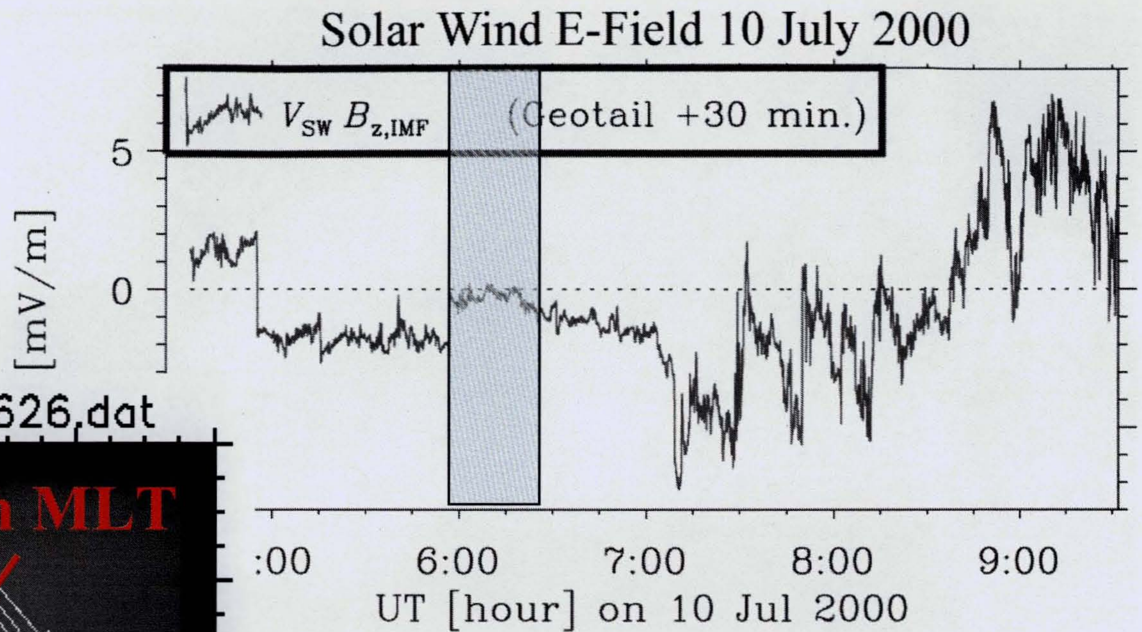
Solar Wind E-Field 10 July 2000
V_{SW} $B_{z,IMF}$ (Geotail +30 min.)
[mV/m]
UT [hour] on 10 Jul 2000

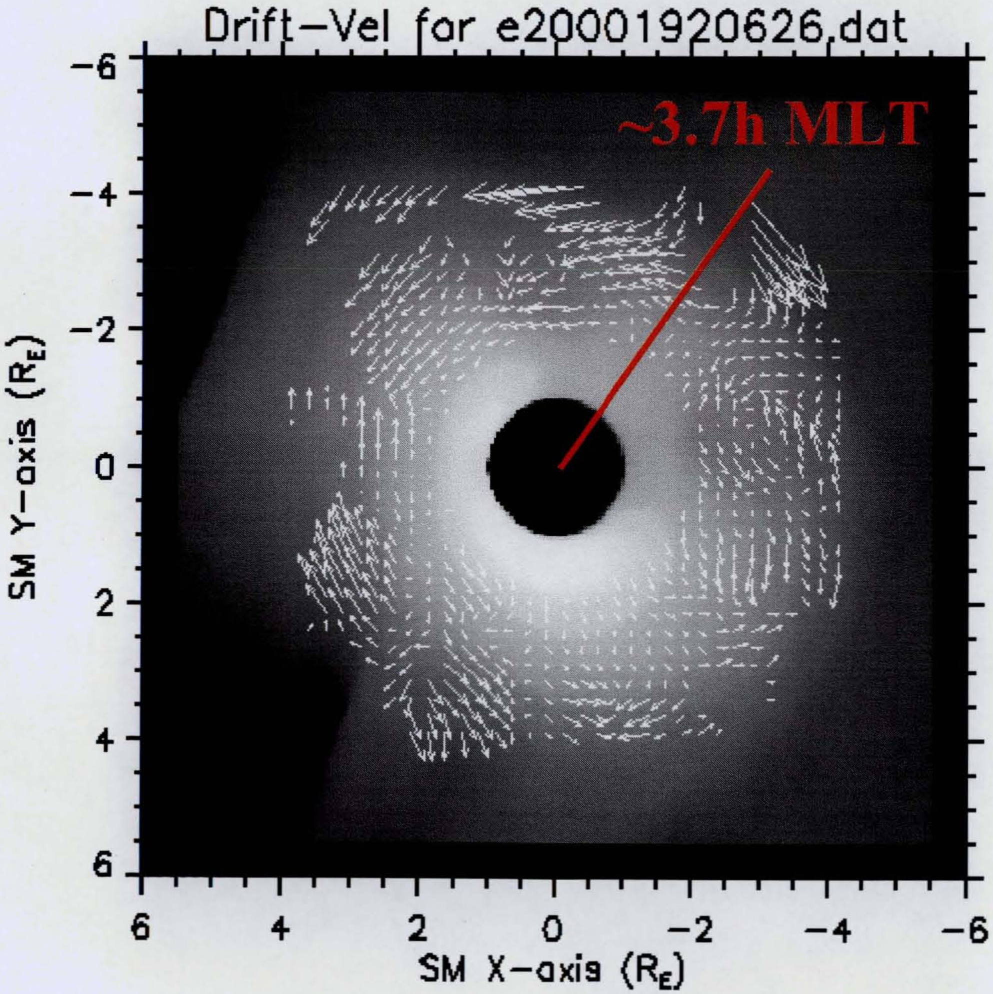


Solar Wind E-Field 10 July 2000
V_{SW} $B_{z,IMF}$ (Geotail +30 min.)
[mV/m]
5
0
:00
6:00
7:00
8:00
9:00
UT [hour] on 10 Jul 2000

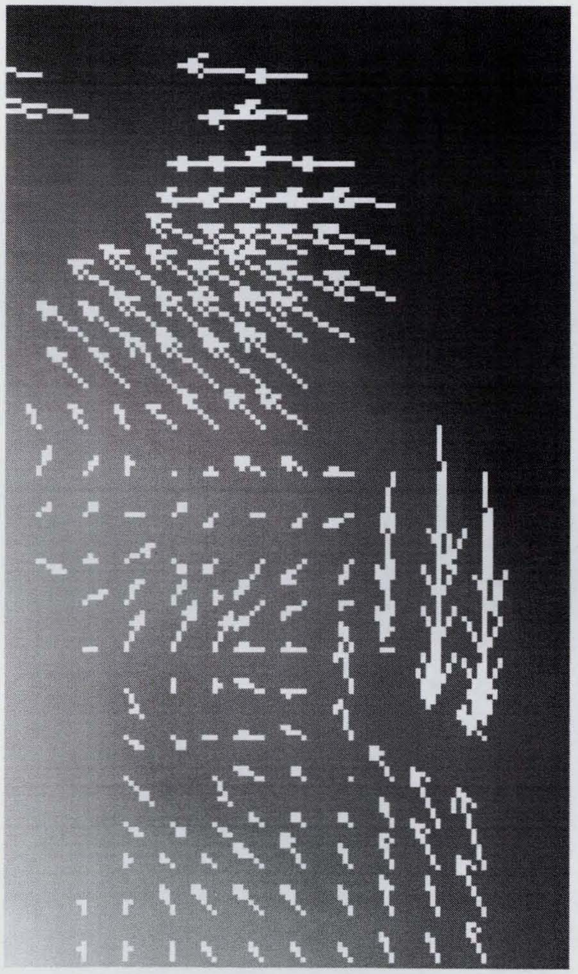


Drift-Vel for e20001920616.dat
~3.3h MLT
SM Y-axis (R_E)
SM X-axis (R_E)
-6
-4
-2
0
2
4
6
6
4
2
0
-2
-4
-6


Solar Wind E-Field 10 July 2000
$V_{SW}\ B_{z,IMF}$ (Geotail +30 min.)
[mV/m]
5
0
:00
6:00
7:00
8:00
9:00
UT [hour] on 10 Jul 2000


Drift-Vel for e20001920626.dat
~3.7h MLT
SM Y-axis (R_E)
SM X-axis (R_E)
-6
-4
-2
0
2
4
6

Summary



- Cross-Correlation analysis appears capable of deriving convective flows broadly throughout the inner magnetosphere
- As suspected, even “simple” plasmaspheric erosion is not so simple
- The technique requires refinement prior to zealous use
- Zealous use of a proven technique is warranted